JOURNAL OF

Petroleum Technology

Volume 1 JUNE, 1949 Number 6

In Two Sections

Section II

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DIRECTORY

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Petroleum Branch Membership

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American Institute
of
Mining & Metallurgical
Engineers, Inc.

Revised to May 20, 1949

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TABLE OF CONTENTS

Officers of the Petroleum Branch f.1
Committees of the Petroleum Branch 3
By-Laws of the Petroleum Branch 5
Directory of Petroleum Local Sections 7
Alphabetical List of Members 13
Geographical List of Members 63
List of Student Associates 79
Officers of the Institute f.84

This Directory published at Dallas, Texas by the Petroleum Branch Special Projects Fund and issued without charge as a convenience to members of the Institute. Its use in connection with the sales promotion of products or services is prohibited.

Journal of Petroleum Technology is published monthly by the American Institute of Mining & Metallurgical Engineers.
Entered as second class matter at New York, N. Y., under the Act of March 3, 1879,
with additional entry at Dallas, Texas.

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BY-LAWS OF THE PETROLEUM BRANCH

(Approved by membership referendum in September, 1946, for adoption March 21, 1947, and amended as to Article IX by membership referendum in 1947.)

ARTICLE I — Name and Object

Section 1. This Branch shall be known as the Petroleum Branch of the American Institute of Mining and Metallurgical Engineers.

Sec. 2. The object of the Petroleum Branch shall be to furnish a medium of cooperation among those interested in the petroleum industry and to promote the advancement of this branch of mineral technology through meetings for professional and social intercourse, and to stimulate the preparation, reading, discussion and circulation of papers connected therewith.

ARTICLE II — Members

Section 1. Any member of the AIME in good standing may become a member of this Branch by indicating in writing that he elects to receive the *Journal of Petroleum Technology* as that monthly publication of the AIME which is to be furnished him at no charge in addition to his dues.

Sec. 2. Only members in good standing in the AIME shall have privileges in the Petroleum Branch.

Sec. 3. Local clubs may be formed by the Petroleum Branch, the membership of which shall be subject to and in accordance with the By-laws of the Institute.

ARTICLE III — Funds

Section 1. The expenditure of funds received by the Petroleum Branch shall be authorized by the Executive Committee of the Petroleum Branch.

Sec. 2. Dues or assessment in addition to the regular dues of the Institute may be fixed by the Executive Committee of the Petroleum Branch, subject to the approval of the Board of Directors of the AIME.

ARTICLE IV — Meetings

Section 1. The Petroleum Branch shall meet as a regular and integral part of the Annual Meeting of the AIME and at such other times and places as may be determined by the Executive Committee of the Petroleum Branch.

Sec. 2. The Annual Meeting of the Executive Committee of the Petroleum Branch, open to its membership, shall be held during the Annual Meeting of the AIME, and special meetings may be called by the Chairman upon thirty days' notice in writing or through *Journal of Petroleum Technology*.

ARTICLE V — Officers

Section 1. The officers of the Branch shall consist of a Chairman and two Vice-Chairmen.

Sec. 2. The Executive Committee shall consist of the officers, the immediately past Chairman of the Branch, and six other members who shall, after the first election under these By-laws, be elected two each year for terms of three years.

Sec. 3. The Chairman of the Branch shall be Chairman of the Executive Committee.

ARTICLE VI — Government

Section 1. The Executive Committee shall be the supreme governing body of the Branch. It shall act subject to the provisions of these By-laws, the Constitution and By-laws of the AIME, and subject to a majority vote of the members of the Branch, initiated under the provisions of Article X. For the transaction of business five shall constitute a quorum. If less than five are present at a business meeting the action of those present shall become final if approved by five members not present.

Sec. 2. The Executive Committee shall fill any vacancies by appointing members for unexpired terms. It shall appoint a Division Treasurer and its own Secretary. It shall prepare a manual covering the functioning of the Division and defining the duties of officers and committee members. It shall replace any committee chair-

man who, for any reason, does not actively prosecute his assignment. It shall make or approve the appointment of all committee chairmen.

ARTICLE VII — Committees

Section 1. There shall be two classes of committees — standing committees and special committees.

Sec. 2. There shall be six standing committees as follows:

Production Technology
Production Review
Economics
Membership
Publications
Education

Sec. 3. The Executive Committee may designate from time to time such special committees as it may consider necessary or desirable. Special committees shall be held to a minimum in number, their duties clearly defined, and dismissed as soon as their report is accepted or they become inactive.

ARTICLE VIII — Eligibility for Office

Section 1. To be eligible for election to the Executive Committee a member shall have had wide experience in the affairs of the Branch.

Sec. 2. To be eligible for Chairman a member shall have had three years of active service in the Branch, at least one of which shall have been as Chairman of a standing committee or as a member of the Executive Committee.

Sec. 3. To be eligible for Vice-Chairman a member shall have had two years of active service in the Branch, at least one of which shall have been as Chairman of a standing or special committee, or as a member of the Executive Committee, or as Chairman of a Local Section.

ARTICLE IX — Nominations and Elections

Section 1. A Nominating Committee of five members shall be appointed by the Executive Committee during the Annual Meeting and submit its report to the Chairman of the Division not later than June 1.

Sec. 2. Any ten members of the Branch may submit nominations to the Executive Committee for one or more positions not later than August 15 and the members so nominated shall be included in the official ballot, providing only they meet the requirements of Article VIII.

Sec. 3. The voting shall be by letter ballot, electing three officers and two members of the Executive Committee annually.

Sec. 4. Section 3 shall apply only when any ten members take the action allowed under Section 2. When no such action is taken the process for election shall be that names and biographies of the Nominating Committee's designees shall be published in the June issue of *Journal of Petroleum Technology*, and upon August 15 the Nominating Committee's designees will be declared by the incumbent Chairman to be automatically elected.

ARTICLE X — Amendments and Petitions

Section 1. Proposals to amend these By-laws shall be made in writing to the Executive Committee and signed by at least 25 members; or shall be made by a majority vote of the Executive Committee. Such proposals shall be published, with discussion, in *Journal of Petroleum Technology* and submitted to the members at the time of the next annual election, or earlier, at the discretion of the Executive Committee. If favored by a majority of the votes cast the amendment shall become effective.

Sec. 2. Proposals to change the decisions, policy, or procedures of the Executive Committee shall be made to it in writing and signed by at least 25 members. Such proposals, unless acceptable to the Executive Committee or withdrawn within 30 days, shall be published, with discussion, in the following issue of *Journal of Petroleum Technology*, and submitted to the members for vote within 60 days after publication. A majority of the votes cast shall be decisive.

AIME PETROLEUM LOCAL SECTIONS

Of the 44 Local Sections of the Institute the 11 listed here are composed almost entirely of members of the Petroleum Branch. Members taking up residence within a Local Section should report their address to the Secretary of the Section to be assured of receipt of notices of meetings, etc. Any meeting places and dates listed here as customary for a Section are subject to change and should be verified.

ARIZONA — See Pacific Petroleum Chapter.

CALIFORNIA

Pacific Petroleum Chapter*

Organized December, 1945

Territorial Limits: All of California and states adjoining California.

Membership Requirements: Residence in territory and membership in the Petroleum Branch.

Meetings: The Chapter, as such, meets at intervals upon announcement. The Production Technology Forum meets on the fourth Monday of each month at the Ethyl Auditorium, 6th and Beaudry, Los Angeles.

Officers: *Chairman* — Paul Andrews, Signal Oil & Gas Co., 811 W. 7th St., Los Angeles. *Vice-Chairman and Sec'y Treas.* — Frank S. Parker, Signal Oil & Gas Co., Los Angeles. **Councilors:** Paul Andrews, L. W. Chasteen, Harold J. Clark, A. W. Gentry, Basil Kantzer, C. T. McClure, John R. McMillan, Frank Parker, Dean H. Sheldon. **Committee Chairmen:** *Membership* — Nelson Williams; *Petroleum Technology Forum* — C. F. Gates; *Field Trip* — F. L. Wadsworth; *Fall Meeting Luncheon* — Basil Kantzer; *Fall Meeting General Chairman* — John H. Thacher, Jr.; ***Journal* Secretary:** Frank S. Parker.

Junior Group

Meetings: Second Thursday of each month at Rio Hondo Country Club, Downey, Calif.

Officers: *Chairman* — C. T. McClure, Youngstown Sheet & Tube Co., 714 W. Olympic, Los Angeles. *Secretary* — I. A. Marshall, Shell Oil Co., Inc., Los Angeles. *Treasurer* — R. L. Parsons. **Committee Chairmen:** *Program* — N. B. Clark; *Membership* — Harold Nissen. **Executive Committee:** All of forenamed plus T. S. Mitchel, ex-officio. ***Journal* Secretary:** I. A. Marshall.

San Joaquin Valley Section

Officers: *Chairman* — Murray Putnam, Standard Oil Co. of Calif., 11-C Camp, Taft, California. *Secretary* — C. L. Doyle. **Committee Chairmen:** *Program* — D. G. Kingman; *Membership* — Max Eastman. **Executive Committee:** All of forenamed.

San Francisco Section

In process of organization at May 20, 1949.

* Administratively not in same status as a Local Section, and not recognized by the Institute as such, but functions in similar manner.

KANSAS

Kansas Section

Organized October, 1948

Territorial Limits: All of the State of Kansas except the portion in southeast corner belonging to Tri-State Section.
Membership Requirements: Residence in territory and Institute membership. Non-members of the AIME are accepted in non-voting "affiliate" status upon payment of $2.50 yearly dues.
Meetings: Monthly except June, July and August in Wichita, Ellinwood, Great Bend, or Lawrence.
Officers: *Chairman*—V. J. Mercier, Lane-Wells Co., 809 Central Bldg., Wichita. *Vice-Chairmen* — D. H. Sholtus, Wichita, and Walter C. Pearson, Ellinwood. *Secretary* — W. F. Brown, Dowell Incorporated, Union National Bank Bldg., Wichita. **Directors:** Chas. F. Weinaug, P. T. Amstutz, Jr., Paul Witherspoon and W. S. Warren. ***Journal*** **Secretary:** Carl Lund, Moorlane Co., Wichita. **Committee Chairmen:** *Awards*—Eugene A. Stephenson; *Membership*—P. T. Amstutz, Jr.; *Publicity*—Carl Lund; *Field Trip*—Paul Witerspoon; *Nominating*—Lamont E. Smith.

LOUISIANA — Also see East Texas Section.

Delta Section

Organized September, 1946

Territorial Limits: That part of the State of Louisiana south of a straight line beginning at the Sabine River, passing through Torras and Fullerton, La., and terminating at the Pearl River, plus that part of the State of Mississippi lying south of 33°30″ north latitude.
Membership Requirements: Residence in territory and membership in the Institute. Non-members of the AIME are accepted in non-voting "affiliate" status upon payment of nominal dues.
Meetings: Second Tuesday of each month, except June, July and August, at the Petroleum Club, New Orleans.
Officers: *Chairman* — E. N. Dunlap, California Research Corp., 1818 Canal Bldg., New Orleans. *Vice-Chairmen* — H. M. Krause, Jr. and Charles R. Blomberg. *Secretary* — Fred E. Simmons, Jr., Louisiana Land & Exploration Co., 1904 American Bank Bldg., New Orleans. **Directors:** H. C. Petersen, Benj. C. Craft, A. Claudet and J. C. Posgate. ***Journal*** **Secretary:** J. Paul Ratliff, Jr., Rey Supply Co., 213 International Trade Mart, New Orleans. **Committee Chairmen:** *Program*—A. Claudet; *House*—C. R. Blomberg; *Publicity*—J. P. Ratliff, Jr.; *Membership* — H. M. Krause; *Activities* — E. N. Van Duzee.

MISSISSIPPI

Mississippi Sub-Section, Delta Section

Territorial Limits: That part of the State of Mississippi south of 33°30″ north latitude.
Membership Requirements: Residence in territory and Institute membership. Non-members of the AIME are accepted in non-voting local status upon payment of nominal dues.
Meetings: Rotated bi-monthly between Jackson, Natchez, Laurel and Brookhaven.
Officers: *Chairman* — R. E. France, The California Co., Box 360, Natchez, Miss.

Vice-Chairmen — Harold B. Luton and J. G. Walvoord; *Secretary* — A. W. Gunther, The California Co., P. O. Box 360, Natchez. **Directors:** Dare Harrell, J. K. Wright, W. A. Ramseur, T. B. Young. ***Journal* Secretary:** Sam Poythress, Jr., Gulf Ref. Co., Laurel, Miss. **Committee Chairmen:** *Membership* — J. K. Wright.

NEVADA — See Pacific Petroleum Chapter.

NEW MEXICO — See Permian Basin Section.

OKLAHOMA

Mid-Continent Section

Organized December, 1917

Territorial Limits: That part of the State of Oklahoma lying north and east of a line running from the northeast corner of Grant County southeastward to Okemah, thence east to Fort Smith, Ark.

Membership Requirements: Residence in territory and membership in the Institute.

Meetings: Second Monday of each month except June, July and August. Study group meetings are held third and fourth Tuesdays of each month except June, July and August. Weekly luncheons on Thursday noon at Bit of Sweeden.

Officers: *Chairman* — Herbert M. Cooley, Bethlehem Steel Co., Bethlehem Bldg., Tulsa; *Vice-Chairmen* — Roy H. Smith and J. N. McGirl; *Sec'y Treas.* — J. H. Beesley, Baroid Sales Div., National Lead Co., 502 Tulsa Bldg., Tulsa. **Executive Committee:** W. H. Horner, W. H. Burke, G. M. Stearns, J. A. Murphy, A. B. Cook and (ex-officio) P. P. Manion, J. P. Hammond, L. E. Elkins and C. V. Millikan. ***Journal* Secretary:** J. H. Beesley. **Committee Chairmen:** *Program* — Roy H. Smith; *Membership* — J. N. McGirl; *Study Group* — John Arps.

Oklahoma City Section

Organized February, 1947

Territorial Limits: All of Oklahoma not within the Mid-Continent Section, plus all of Texas (Panhandle) north of the southern boundaries of Deaf Smith, Randall, Armstrong, Donley and Collingsworth Counties.

Membership Requirements: Residence in territory and membership in the Institute.

Meetings: Usually in the second week of each month except June, July and August.

Officers: *Chairman* — Lincoln F. Elkins, Sohio Pet. Co., 2300 First National Bank Bldg., Oklahoma City. *Vice-Chairmen* — Henry Waszkowski, Oklahoma City, and N. van Wingen, Norman. *Sec'y-Treas.* — Martin O. Hegglund, Stanolind Oil & Gas Co., Box 1654, Oklahoma City. **Executive Committee:** R. J. Beams, C. E. Clason, H. L. Sells, L. F. Elkins, H. L. Waszkowski, N. van Wingen and M. O. Hegglund. ***Journal* Secretary:** Harold Sells, Sohio Pet. Co., 2300 First National Bank Bldg., Oklahoma City. **Committee Chairmen:** *Membership* —David L. Dooley; *Publicity* — Harold Sells.

OREGON — See Pacific Petroleum Chapter.

TEXAS — See also Oklahoma City Section.

East Texas Section
Organized April, 1940

Territorial Limits: Northeastern Texas and that part of the State of Louisiana north of a line from the Sabine River through Torras and Fullerton, La., to the Pearl River.

Membership Requirements: Residence in territory and membership in the Institute. Non-members of the AIME are accepted in non-voting "local" status upon payment of nominal dues.

Meetings: Monthly except June, July and August; usually in Kilgore, occasionally in Shreveport.

Officers: *Chairman* — Jack M. Shepherd, Humble Oil & Ref. Co., Tyler; *Vice-Chairman* — W. W. Leonard, Box 44, Shreveport; *Sec'y-Treas.* — R. F. Beery, Jr., Shell Oil Co., Inc., Premont, Texas. **Directors:** John S. Bell, Robt. M. Hess, W. M. Jones, L. H. Dial, P. J. Lehnhard, R. T. Wade. ***Journal* Secretary:** R. F. Beery, Jr. **Committee Chairmen:** *Program* — Roland K. Thies; *Membership and Attendance* — T. L. Forehand; *Audit* — Riley Aucoin.

Gulf Coast Section
Organized December, 1935

Territorial Limits: Gulf Coastal portion of Texas from Sabine River on east to Colorado River on west.

Membership Requirements: Residence in territory and membership in Institute. Non-members of the AIME are accepted in non-voting "local" status upon payment of nominal dues.

Meetings: Third Tuesday of each month except August and December at the YMCA in Houston.

Officers: *Chairman* — Owen F. Thornton, The Texas Co., Box 2332, Houston; *Vice-Chairmen* — E. B. Miller, Houston, George Fancher, Univ. of Texas, A. B. Stevens, A&M College of Texas; *Sec'y-Treas.* — A. G. Gueymard, Pet. Dept., City National Bank, Houston. **Directors:** R. W. Wilson, L. V. Uhrig, G. L. Nye, Fred Nelson, G. D. Robertson. ***Journal* Secretary:** J. E. Kastrop, Gulf Publishing Co., 3301 Buffalo Drive, Houston. **Committee Chairmen:** *House* — K. B. Ford; *Publicity* — J. E. Kastrop; *Activity* — L. W. Huebel; *Program* — E. L. Petree; *Membership* — E. A. Rassinier; *Houston Engineers' Council* — George R. Gray.

North Texas Section
Organized May, 1945

Territorial Limits: Forty-four counties of North Central Texas.

Membership Requirements: Residence in territory and membership in Institute.

Meetings: Monthly except June, July and August. Rotated between Dallas, Fort Worth, and Wichita Falls.

Officers: *Chairman* — Don L. Harlan, The Texas Co., P. O. Box 1720, Fort Worth; *Vice Chairmen* — J. A. Crichton, Dallas, I. E. Curtis, Wichita Falls; *Sec'y-Treas.* — Patrick H. Reardon, Gulf Oil Corp., P. O. Box 1290, Fort Worth.

North Texas Section — Continued

Directors: E. E. Merkt, W. D. Sorrells, D. H. Clewell, L. P. Whorton, Tom E. Morton. ***Journal* Secretary:** Kenneth Anderson, U. S. Bureau of Mines, Santa Fe Bldg., Dallas. **Committee Chairmen:** *Military Intelligence* — Lt. Col. J. A. Crichton; *Program* — Wm. E. Stiles, Dallas, Paul M. Wiley, Fort Worth, Roland Gouldy, Wichita Falls; *Membership* — Sam DeWitt, Dallas, W. B. Watson, Fort Worth, H. K. Holland, Jr., Wichita Falls; *Hospitality and Entertainment* — A. Ed Caraway, Dallas, Steven Gerolde, Fort Worth, Tom Morton, Wichita Falls. *Publicity* — K. Marshall Fagin, Dallas, Gus Athanas, Fort Worth, I. E. Curtis, Wichita Falls.

Permian Basin Section

Organized November, 1945

Territorial Limits: West Texas, limited on the south by the northern boundaries of Valverde, Edwards, Kerr, and Kendall Counties, and on the north by the southern boundaries of Deaf Smith, Randall, Armstrong, Donley and Collingsworth Counties.

Membership Requirements: Residence in territory and membership in Institute. Non-members of the AIME are accepted in non-voting "local" status upon payment of nominal dues.

Meetings: Monthly, in either Midland or Odessa.

Officers: *Chairman* — Thomas C. Frick, The Atlantic Ref. Co., Box 871, Midland; *Vice-Chairman*—W. N. Little; *Sec'y-Treas.*—J. M. Moore, Dowell Incorporated, Box 1848, Midland. **Directors:** Thomas C. Frick, W. N. Little, J. M. Moore, Burton Atkinson, Lamar Lunt, W. L. Crothers. ***Journal* Secretary:** Tom Flewharty, The Western Co., Midland. **Committee Chairmen:** *Program* — W. N. Little; *Membership* — Joe Chastain.

Southwest Texas Section

Organized September, 1946

Territorial Limits: Southernmost portion of Texas Gulf Coast, bounded on east by Colorado River, on west by Rio Grande River, and on north by Colorado River and northern boundaries of Val Verde, Edwards, Kerr, Kendall, Comal, Caldwell and Fayette Counties.

Membership Requirements: Residence in territory and membership in Institute. Non-members of the AIME are admitted in non-voting "local" status upon payment of nominal dues.

Meetings: Monthly on second Wednesday, at Corpus Christi.

Officers: *Chairman* — Raoul J. Bethancourt, Sun Oil Co., Box 2431, Corpus Christi; *Vice-Chairman* — Chas. H. Snelson; *Sec'y-Treas.* — R. C. Granberry, Jr., Humble Oil & Ref. Co., Box 1271, Corpus Christi. **Directors:** Emil Bowers, Barrett Booth, H. L. Moseley, L. J. Thronson, H. N. Lyle. ***Journal* Secretary:** Raymond Keller, Jr., Seaboard Oil Co., Corpus Christi. **Committee Chairmen:** *Program* — Houston Parish; *Membership* — H. L. Moseley; *Entertainment* — J. B. Jones.

ALPHABETICAL LIST OF MEMBERS

NOTE: Members who have so elected are indicated as being "available for consulting work" in the geographical list, commencing on page 63.

Aaring, Floyd D., Pet. Engr., Canadian Gulf Oil Co., P. O. Box B-4, Pincher Creek, Alberta, Canada.

Abadie, Henry G., Senior Prod. Engr., Long Beach Oil Development Co., 255 S. Santa Clara Ave., Long Beach 7, Calif.

Abbott, Robert H., Jr., Pet. Engr., The Texas Co., Box 951, Houma, La.

Abbott, R. W. R., Asst. Power Supt., Cananea Consolidated Copper Co., Cananea, Son., Mexico.

Abel, Raymond L., Prof. of Chem. Engr'g, Univ. of Pittsburgh, 203 State Hall, Pittsburgh 13, Pa.

Abel, Walter D., Mining & Pet. Engr., Div. of Corporations, State of Calif., Rm. 800, 145 So. Spring St., Los Angeles 12, Calif.

Abernathy, Gene E., Pet. Engr., Prod. & Drill., Dept., Mid-Cont. Div., Signal Oil and Gas Co., 506 Danciger Bldg., Ft. Worth 2, Texas.

Abernathy, Jack H., V. Pres., Big Chief Drilling Co., 2810 First National Bldg., Oklahoma City, Okla.

Abraham, A. W., Pet. Engr., Richfield Oil Corp., 555 S. Flower St., Los Angeles, Calif.

Abrams, Armand Jean., Asst. Mgr., Chem. Dept., Engr'g & Const. Div., Koppers Company, Inc., Koppers Bldg., Pittsburgh, Pa.

Abrams, Frank W., Chm. of Bd., Standard Oil Co. (New Jersey), Room 2916, 30 Rockefeller Plaza, New York 20, N. Y.

Abreu, Sylvio F., Rua Dr. Satamini 129, Rio de Janeiro, Brazil, S. A.

Acher, Ross M., Field F'man, The Texas Co., Rt. 1, Box 2000, Seminole, Okla.

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DeGolyer, E. L.
DeWitt, S. N.
Dimit, C. E.
Dismukes, N.B.
Dougherty, J. F.
Dunlap, H. F.
*Fagin, K. M.
Fisher, B.
Fuller, J. S.
Garrett, M. M.
*Gilmore, R. B.
Gordon, J. C.
Graham, G. L.
Green, W. R.
Gregg, C. E.
Gruy, H. J.
Hager, D. S.
Hansell, J. M.
Harter, C. C., Jr.
Hawkins, D. E., II
Hawthorne, R. R.
Heath, F. E.
Heithecker, R. E.
Heroy, W. B.
Hilseweck, W. J.
Holman, H. H.
Holmes, H. P.
Hudson, C. H.
Jackson, W. J.
Jacobs, J. C.
James, J. R.
Johnson, L. N.
Johnson, W. O.
*Jopling, D. W.
Karcher, J. C.
Keating, J. P.
Keiles, M. E. C.
Kelton, F. C.
Kennerly, T. L.
Kieschnick, W. F., Jr.
Koepf, E. H.
Kollar, R. E.
Kraus, E.
Kuhn, C. S., Jr.
Kuhne, E. B.
Lahee, F. H.
Lancaster, G. G.
*Lewis, J. A.
Lipson, L. B.
Loring, W. T.
Lowe, J. P., Jr.
MacNaughton, L. W.
Marshall, D. L.
Mayes, G. C.

Dallas.—Continued.
McClain, H. M.
McClintock, H. P.
*McCoy, G. Y.
McDermott, E.
McElheny, O. K.
McFarland, R. S.
McLaughlin, D. C.
McLeod, A.
Mehan, J. A.
Meredith, C.
Meyer, W. G.
Miller, C. C.
Mills, B.
Minton, J. P.
Moir, B. E.
Monkhouse, G. S.
*Morgan, C. G.
Murray, F. F.
Murrell, J. H.
Myers, R.
Nathman, G. P.
Nelson, T. W.
*Nichols, E. A.
Nobles, M. A.
Noyes, J. A.
Oldham, A. E.
Otis, H. C.
Ottinger, N. H.
Owens, D. E.
Pabst, A. G.
Page, J. S.
Patton, E. C., Jr.
Philipp, E. R.
Pollard, T. A.
Porter, P.
Potter, L. T.
Pounders, C. M. P.
Powell, W. K.
Priddy, A. H.
Prutzman, F. G.
Ransone, W. R.
Reichertz, P. P.
Renfro, H. B.
Rhea, A. S.
Rhodes, C. L.
Rice, G. B.
Rider, C. R.
Roark, G. E.
Rosaire, E. E.
Rubin, L.
Samuell, J. H.
Saunders, D. L.
Schultz, F. A.
Schwarz, M. E.
Selater, K. S.
Seale, R. I.
Shaw, D. J.
Slobod, R. L.
Smith, A. J.
Smith, E. W.
Smith, G. L.
Speaker, W. H.
Spencer, M. G.
Stade, P. W., Jr.
Stekoll, M. H.
Stepp, V. E.
Stiles, W. E.
Stormont, D. H.
Strang, W. H.
*Stults, A. C.
Sullivan, J. H.
Taubman, L.
Taylor, E. F.
Terrell, K. V.
Thompson, S. A.
Tinker, N. A., Jr.
Tracy, L. E.
Trostel, E. G.
Trout, K., Jr.
Tynes, W. A.
Umpleby, J. B.
Waters, K. H.

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Watson, R. E.
Wayman, G. S., Jr.
Westcot, F. S.
Whorton, L. P.
Williams, C. C.
Williams, D. C.
Wilson, C. C.
Wilson, M. E., Jr.
Woodward, G. E.
Woodward, J. S.
Workman, A. E.
Young, C. A.
Zorichak, J. J.

Delmita.—Birdwell, W. R.

Denver City.—Albers, R. M.
Cawley, A.
Judson, E. H.
Fields, R. E.
Trimble, R. D., Jr.

Dickinson.—Person, R. F.

Dumas.—Ball, D.
Davidson, G. A.

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Payton, J. M.

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Nance, B. J.

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Grimshaw, W. F.
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Schmitt, T. C.
Strain, W. S.

Fairbanks.—Sinex, B. J.
Smith, L. W.

Falfurrias.—Kelley, C. W., Jr.
Long, F. E.

Fischer Store, Comal County.—
McIver, D. T.

Florey.—Jones, N. N.

Ft. Sam Houston.—Silsbee, J. A.

Fort Worth.—*Abernathy, G. E.
Allen, A. C.
Athanas, G.
Awalt, C. A.
Bass, P. R.
Bayer, H. M.
Brockett, E. D., Jr.
Brown, A. R.
Brook, E. J.
*Casteel, S. H.
Christie, R. S.
*Clark, H. S.
Clay, J. A., Jr.
Collins, R. W.
Darney, R. P.
Davis, J. A.
Dean, P. C.
Dilger, R. J.
Donoghue, D.
Eginton, L. G.
Ellis, G. L.
Elner, R.
Erwin, R. W.
Evans, J. R.
Farris, J. C.
Finney, M. A.
Fisher, G. H.
Forbes, H. F.
Gearhart, D. R.
Gerolde, S.
Greenidge, S. M.
Gregory, P. P.
Grommon, P. D., Jr.
Handy, M. A.
Hardwicke, R. E.

Ft. Worth.—Continued.
Harlan, D. L.
Hatfield, F. E.
Hill, J. E.
Holder, L. E., Jr.
Holley, R. J.
Holsapple, L. D.
Howard, K. C.
Jones, T. T.
Kelly, R. B.
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Knode, W. F.
Koch, H. A.
*Kyner, R. R.
Lovejoy, J. B.
Maxwell, J. C.
McLemore, R. H.
Merkt, E.E., Jr.
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Miller, B. J.
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Nuss, W. F., Jr.
Osmond, C. H.
Pearce, W. A.
Pishny, C. H.
Pearson, G. T.
Rantala, R. H.
Reardon, P. H.
Roark, R. E.
Rowan, A. H.
*Sanders, C. W.
Shannon, J. P.
Smith, J. N.
Smith, R. B.
Sorrells, W. D.
Schaeffer, W. A., Jr.
Taylor, M. I.
*Tesch, R. W., Jr.
Thomas, J. E.
Thompson, B. E.
Van Zant, J. H.
Ward, J. C.
Wiley, P. M.
Wilsey, L. E.
Wilson, J. H.
*Weiner, C.

Freeport.—Bybee, P. D.
McMillen, G. C.
Sampson, C. M.

Freer.—Murphy, G. J. W.
Peters, C. B.

Gainesville.—Cain, P. H.
George, E. R.
Mathews, S. J., Jr.
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Gladewater.—Miles, J. N.
O'Neill, L. P.

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Kennerly, K. S.

Graham.—Parrish, F., Jr.

Greggton.—Kerr, J. F.
LaRue, J. W.
Ludwick, R.
Raywinkle, B. E.
Reynolds, B. W.
Wiginton, W. H.

Hawkins.—McLaren, C. F., Jr.

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Goodwin, R. J
Sullivan, A. G.

Houston.—Adams, G. R.
Albertson, M.
Alcorn, I. W.
Allen, C. M.
Allen, H.
Austin, J. W.

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Armstrong, E. N.
Arnold, I.
Ashford, J. T.
Austin, J. W.
Bailey, J. E.
Baker, W. L.
Baker, W. A., Jr.
*Barbour, W. B.
Barclay, S. A., Jr.
Barnes, J. A.
Barnhart, P. F.
Barry, J. O.
Battle, J. L.
Baucum, A. W.
Bayle, P.
Beach, W. D.
*Beatty, R. M.
Beardmore, H. F.
Beck, H. J., Jr.
Beezley, J. E.
Beilharz, C. F.
Belchic, G., Jr.
Bell, Olin G.
*Bennett, E. O.
Bennett, V. D.
Bernhard, W. E.
Bielstein, W. J.
Black, J. P.
Blanchard, A.
Blau, L.
Bloom, B.
Bonner, L. E.
Booth, B. E.
Borland, T. C.
Born, H. R.
Boyce, J. V.
Bozeman, J. W.
Breitung, C. A.
Bridges, R. E.
Bridges, T. J.
Briggs, F.
Brown, C. W.
Brown, G. R.
Brown, H. W.
Brown, H.
Bruyere, A.
Buchan, R. C.
Buck, E. O.
Buckley, S. E.
Bugbee, J. M.
Burns, A. L., Jr.
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Caldwell, J. A.
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*Cantrell, R. B.
Carlton, D. P.
Cartwright, L. D., Jr.
*Cashin, D'A. M.
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Charrin, P. J.
Chenoweth, R. C.
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Christensen, S. H.
Chun, H. A.
Clark, N. J.
Cockrell, E., Jr.
*Collett, J. D.
Conrad, C. S.
Cooke, M. M.
Coultrup, J. G.
Crake, W. S.
Crandall, J. R.
Crawford, W. N., III
Craze, R. C.
Crego, W. O.
Crosby, D. W.
Crowder, J. J.
Cruce, R. V.
Cummings, L. L.
Dansby, R. E.
David, Henry.
Davis, M. J.
Davis, R. E.
Davis, W. K.

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DeMenil, J.
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*Deussen, A.
*Dixon, P. C.
Dodd, J. G.
Doherty, W. T.
Domercq, J., Jr.
DuPont, H. A.
Duran, R. J.
Durst, R. T.
*Eby, J. B.
Eckel, J. E.
Elmdahl, B. A.
Erdman, N. W.
Evans, J. B.
Everett, W. B., Jr.
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*Ferguson, H. C.
Flaitz, J. M.
Florence, W. W.
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Foltz, R. C.
*Ford, K. B.
Ford, R. D.
Forney, L. B.
Foster, J. L.
Frier, I. A.
Fuson, T. J.
*Gallie, J. F.
Gardescu, I. I.
Garfield, L. E.
Garrison, A. D.
Getzendaner, A. E.
Glanville, J. W.
Glasser, I. M.
Goatley, J. H.
Goldston, W. L.
Gordon, D.
Graham, R. C.
Gray, G. R.
*Gray, S. G.
Gregg, C. E.
Griffin, W. H.
Grosjean, R.
Grossman, W. L.
Guest, H. G.
Gueymard, A. G.
Haeberle, F. R.
Hagen, C. V.
*Halbouty, M. T.
Haltom, G. H.
Hamilton, R. G.
Hamman, J., Jr.
Hardin, G. C., Jr.
*Harrison, R. W.
Hasselmann, K. F.
Hawthorn, D. G.
Hayes, E. P.
Heinen, L. E.
Hellums, E. C.
Henquet, R.
Herbert, W. F.
Herring, L. B.
Hill, E. C.
Hocott, C. R.
Holman, O. K.
Holmes, J. B.
Holmesly, S. F.
Hopkins, H. F.
Hopkins, W. B.
Hopkins, W. H.
Hoss, R. L.
Hotze, E. G.
House, G. C.
Howard, D. S., Jr.
Howard, L. B.
Hubbard, E. P.
Hubbard, W. E.
Hubbert, M. K.
Huber, T. A.
Huebel, L. W.

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Huff, J. E., Jr.
Humber, J. B.
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*Ikins, W. C.
Ivy, J. S.
*Jackson, F. G.
Jennings, J. M.
Joplin, J. L.
Jennings, P. H.
*Jones, P. J.
Jordan, J. K.
Judson, S. A.
Kastrop, J. E.
Keating, T. W.
Kemp, E. G.
Kerr, R. A.
Kingelin, G. G.
Kinley, J. C.
Kirkpatrick, C. V.
Kneale, W. C.
Kokas, F. J.
Krueger, W. F.
Laird, J. A.
Lamont, N.
Lancaster, E. H., Jr.
Landau, H. L.
Lasky, B. H.
Lavery, C. C.
Leavenworth, P. B.
Leisk, C. W.
Legeron, R.
*Leonardon, E. G.
Leverett, M. C.
Leverett, W. H.
*Levy, A. G.
*Lewis, J. O.
Lewis, K. S.
Ley, R. P.
Lightfoot, J. H.
Lilley, H. B.
Little, D. D.
Long, A. J.
Louden, E. W.
Lloyd, J. M., Jr.
Lovering, F. F.
Lyons, R. T.
Marr, J. D.
Marr, R. C.
Martin, C. A., Jr.
Mason, W. D., Jr.
Mayfield, M. L.
*McCarter, W. B.
McCarty, D. G.
McCaslin, L. S., Jr.
McCauley, D. W.
McDannald, R. M.
McGhee, V. T.
McLain, J. M.
McNeese, C. L.
McNeill, E. L.
Meers, R. J.
*Mendell, W. T.
Meredith, B.
Meyer, K. E.
Michaux, F. W.
Milburn, J. D.
Miller, E. B., Jr.
Miller, M. G.
Miller, W. M., Jr.
Miner, W. H.
Mitchell, R. B.
Moir, J.
Montgomery, J. C.
Montrose, M. E.
Moore, A.
Moore, J. I.
Moore, S. C.
Morgan, B. E.
Morris, W. D.
Morse, R. R.
Murphy, P. C.
Murchison, J. W., Jr.
Murray, J. R.
Neale, J. J.
Nelson, F. M.

Houston.—Continued.

Neuhaus, R.
Neuman, L. J.
Newman, J. A.
Newsome, J. A., Jr.
Noordhuis, T.
Nye, G. L.
Oberg, S. W.
O'Donnell, L.
O'Leary, G.
O'Neill, H., Jr.
Oliphant, S. C.
Otto, H. A.
Paganini, O.
Palmer, A. B.
Parkans, S. A.
Parks, A. S.
Parks, M. H.
Payne, J. M.
Pennington, J. V.
Pennington, T.
Petree, E. L.
Pew, T. W.
Phillips, C. E.
Phillips, F. G.
Pistole, H.
Plaza, J. B.
Polk, A. C., Jr.
Porter, J. W.
Prokop, C. L.
Poyner, H. F., Jr.
Purcell, W. R.
Pyburn, T. D.
Rabson, G. H.
Ragland, D.
Ray, R. H.
Reasoner, M. A.
Redmon, C. F., Jr.
Reed, C. F.
Reed, C. M.
Reed, E. M.
Reistle, C. E., Jr.
*Reiter, W. A.
Remick, D. B.
Reynolds, F. S.
Rhea, J. W.
Richardson, J. G.
Rieke, R. R.
Roberts, O. A., Jr.
Robertson, G. D.
Robertson, L., Jr.
Robishaw, E. J.
Rolshausen, F. W.
Ross, E.
Ross, J. A., Jr.
*Runion, F. A.
Russell, C. A.
*Russell, G. F.
Rust, W. M., Jr.
St. Germain, R. J.
Salathiel, R. A.
Sawtelle, G. F.
Scamman, C. W.
Schilthuis, R. J.
Scholl, L. A., Jr.
Scown, E. A.
*Selig, A. L.
Sharp, C. S.
Shearer, L. H.
Sherar, S.
Shively, C. W.
Sides, J. M.
Smith, E. W.
Smith, H. V.
Smith, J. W.
Smith, R. H.
Sowers, J. C., Jr.
*Spoor, H. C., Jr.
Stallworth, D. C.
Stamm, H. E.
Stanwood, R. D.
Swan, W. A.
Swanson, L. A.
Sweet, J. D.
Swigart, T. E.
Taylor, R. E.

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*Teague, J. U.
Teas, L. P.
Thomas, B.
Thornton, O. F.
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Timmerman, E. H.
*Todd, J. D.
Torrey, P. D.
Tower, D.
Trott, D. E.
Trube, A. S.
True, M. E.
Turner, D. D.
Uhrig, L. V.
Van Burgh, L. R.
Van Dyke, O. W.
van Everdingen, A. F.
Vaughan, W. H.
Vietti, W. V.
Waddill, A. W.
Waechter, J. W.
Walker, J. W.
Wallace, P. P.
Warner, C. A.
Waterman, L. C.
Watson, J. P., Jr.
Wear, J. M.
Weiler, J. F.
Welsh, J. R.
*Welsh, L. G.
*Whatley, W. J.
Whitman, A. D.
Wickstrom, S. A.
Wilde, H. D.
Willits, M. H.
Williams, M.
Wilson, R. W.
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Winkelmann, S. A.
Wright, P. C., Jr.
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*Young, T. B.

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Kamay.—Spires, H. D.

Katy.—Lindauer, R. L., Jr.
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Kermit.—Bresenham, J. J., Jr.
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Goodrich, J. S.
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Beery, R. F., Jr.
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Dial, L. H.
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Ford, O. J., Jr.
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Ivie, W. W.
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LaRoe, D. M.
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Long, H. L.
Mays, W. R.
McArthur, H. K.
Morgan, J. A.
Morris, W. S.
Nussbaumer, F. W.
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Wilson, D. A.

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*Ducker, W. L.
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Leibrock, R. M.
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Nabors, F. L.
Whitis, E. D.

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Trout, W. W.

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Neath, R. A.

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McGee, C. J.
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Patterson, H. L.
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Thronson, L. J.
Yarborough, R. W.

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Russell, R. W.
Willis, L. J.

Mexia.—Liddle, R. A.

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Blackwood, J. C.
Brennan, H. W., Jr.
Brown, P. F.
Campbell, T. B.
Cawthon, P., Jr.
Chastain, J.
Chiles, H. E., Jr.
Clements, F. H.
Convers, F. L.
Cooper, C. G.
Crawley, J. B.
Crittenden, J. L.
Crothers, W. L.
Curtis, T. M.
Denson, B. L.
Dewey, R. S.
Dennelly, A. S.
*Faris, C. M.
*Fitting, R. U., Jr.
Fitting, R. D.
Floyd-Jones, M. J.
Flood, L.
Foell, F. W.
Folger, F. C., Jr.
Frick, T. C.
Grant, L. S.
Gray, G. H.
Graybeal, J. W.
Greer, J. W.
Haigh, B. R.
Hardison, H.
Heald, K. C.
Henderson, G. H.
Henderson, W. D.
Hills, J. M.
Hinson, B. J.
Howard, R. E.
Kitley, D. V.
Latham, L.
Lawton, J. L.
Little, W. N.
*Lunt, L.
Matthews, C. C.
Maverick, P., Jr.
McCullar, R. B. L.

Midland.—Continued.
*McCutchin, J. A.
McMillen, R. E.
Meisenheimer, D. B.
*Montgomery, W. J.
Moore, J. M.
Moore, J. L.
Morazzani, A.
Norris, H. J.
Payne, C. W.
*Penn, W. Y.
Perusek, C. J.
Peterson, L. F.
Randerson, L. W.
St. Clair, D. W.
Schaeffer, W. A., III
Schaeffer, W. A., Jr.
Schafer, J. D.
Senning, R. C.
Shakely, E.
Smith, E. L.
Sybert, J. H.
Thawley, L. H.
Van Meter, O. E., Jr.
*Wahlstrom, E. A.
Warren, J. E.
Weaver, B. R.
Wheeler, J. D.
White, G. H.
Wood, L. B.
Younger, J. F.

Mineral Wells.—*Brown, J. L.

Newgulf.—Treichler, H. E.
Treichler, H. E., Jr.
Zemanek, A. F.

Nocona.—Barton, R. A., Jr.

Nordheim.—Nolan, W. E.

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Mueller, C. B.

Odem.—Brady, H. J.

Odessa.—Bethancourt, H. L.
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Hamilton, H. M.
Hardee, P., Jr.
Harrell, J. B., Jr.
Henley, J.
Hussey, C. B.
Kendall, E. C.
LaLonde, C. M.
Main, M. K.
McCutchen, R. C.
Rabe, C. L.
Rodman, E. G.
Scott, W. A.
Shanor, P. J.
Shields, R. C.
Shilcutt, C. M.
Thrash, J. C., Jr.
Utermohle, G. E., Jr.
Wright, J. C.

Overton.—Byrd, L. H.
Furse, O. L.
Leeman, S. P.

Palacios.—Trull, R. B.

Pampa.—Cox, J. L.
Sibley, W. P.
Tripp, K. R.

Pearsall.—Pickett, G. B.

Pettus.—*Jones, E. N.
Mast, D. T.

Pickton.—Hunt, C. N., Jr.
Yust, C. S.

Pierce.—Walts, C. W.

Pleasanton.—Davis, W. S.
Richards, W. E.

Premont.—Angelli, O.
Coil, C. L.
Dayton, M., Jr.
Jones, D. E.
Staples, D. R.
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Wilson, C. W.
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Brown, A. B.
Cooper, H. H.
Davis, F. M.
Davis, T.
Donzis, J. M.
*Gunby, D. F.
Guthrie, R. K.
Hammond, W. W.
Klaeger, E. J.
Lehecka, C. E.
McCarroll, C. F.
Moore, P. J.
Osmond, J. C., Jr.
Owen, E. W.
Petty, D. E.
Petty, O. S.
Rollin, G. S.
Rosser, W. H.
*Rowden, D. H.
Schmidt, K. H.
Schoolfield, R. F.
*Scrafford, J. B.
*Shaw, S. F.
Sloss, J. P.
*Spice, W. H., Jr.
Stapp, W. L.
*Swearingen, J. S.
Upchurch, M.
Vogel, F. A., Jr.
Warner, R. E.
Warner, T.
West, T. S.
Seagraves.—Frack, M. W.
Hutchins, C. H.
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Kittrell, N. G.
Sherman.—McMahan, J. M.
Silsbee.—Penrod, J. M.
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Snyder.—Mims, C. D.
Stowell.—Chandler, D. E.
Sundown.—Edwards, F. C.
Sweeny.—Augsburger, C. H.
Castleton, H. W.
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Sweetwater.—
Anderson, G. E., Jr.
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Grelling, L. A.
*Hudnall, J. S.
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Davidson, K. B.
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*Fagadau, S. H.
*Fosdick, A. R.
Gouldy, R.
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Hollow, W. B.
Huffman, E. A.
*King, R. H.
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Lenz, W. C.
Lewis, V. E.
Maucini, J. J.
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Freeze, J. P.
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Landon, R. E.
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Wilson, E. D.
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*Link, T. A.
Schneider, A. L.
*Stee, C. O.
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Wheeler, O. C.
Wallace, W. S.

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Quebec.—Jones, I. W.
Letendre, G.

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de la Garza Cardenas, J. M.
*de la O, A. C.
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Hefferan, J. V.
Kail, R. S.
Moran, L. M.
Rios-Zurtuche, A.
Velasco, C.

HIDALGO

Taxco.—Crosby, J. C.

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Cananea.—Abbott, R. W. R.

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Tampico.—Cochran, R. B.
Guzman, E. J.
Pangtay, J. T.

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Huerta, E.
Straffon, A. A.
Poza Rica.—Saucedo, R. L.

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NICARAGUA

Managua.—Young, F.

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Pointe-A-Pierre.—Suter, H. H.
Port of Spain.—Goodwin, J. A.
San Fernando.—Richards, G. A.

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Martinez, J. O.
Chubut.—Isherwood, J. D.
Salta.—Chapman, C. E.
Soler, J. F.
Vte. Lopez.—Bruner, H.

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Osborne, P. F.
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de Oliveira, A. I.
Garner, A. H.
Morris, L. K.
Oddone, D. S.
Sao Paulo.—de Camargo, W. G. R.
Moraes, J. E.

CHILE

Magallanes.—Simian, E. G.
Punta Arenas.—Porter, J. L.

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Chapman, I. T.
Bogota.—Acosta-Sarmiento, G.
Amorocho, J.
Bower, J. O.
Brineman, J. H.
Campbell, C. V.
Chappell, W. M.
Connor, E. J.
Cuervo, A. G.
Dobson, E. G.
Fulton, J. M.
Bogota.—Continued.
Hatfield, W. C.
Keppel, D.
Lager, A. F.
Lytel, H. M.
Mejia, J.
*Oppenheim, V.
Ospina-Racines, E.
Parker, G.
Parsons, H. E.
Pollard, P.
Roeseler, W. T.
Suman, J. R., Jr.
Taitt, G. S.
Cucuta.—Bowen, W. G.
Hubbard, W. B.
Isakson, C. O.
Wroten, P. O.
El Centro.—Cavidad, O. S.

PERU

Cuzco.—Gibson, J.
Lima.—Belon, E. T.
*Levangie, G. W.
Mason, H. C.
Plenge-W., C. H.
Williams, M. D.
Talara.—Carroll, H. C.
Kitterman, J. W.

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Allaud, L. A.
Cirigliano, J.
Cox, W. J.
Dawson, G. W.
Fitzgerald, W. H.
Maddox, A.
Patton, W. R.
Roberts, C. C.
Sass, L. C.
Sherman, H.
Trujillo, O. A.
Walker, E. B., III
Weaver, H. B.
Wickenhauser, L. J.
Cabina.—Stagg, B. J.
Caracas.—Allen, L. D.
Anglade, A. S.
Battisti, J. M.
Benge, G. J.
Bunke, P. K.
Caan, A. J. Z.
Cole, A. B.
Conrad, P. P.
Dahlberg, R. S., Jr.
Dallmus, K. F.
de Juana, C. G.
Eager, E. E.
Floyd, F. W.
Fricke, K. S.
Galavis, S. J. A.
Gillingham, W. J.
Fowler, C. W., Jr.
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Grim, G. R., Jr.
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Hall, W. M.
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Herrera, F. L.
Hill, R. G.
Hodell, L. R.
Holmes, J. A.
Horton, H. M.
Iribarren, M.
Jones, V. E.
Kelso, E. F.
Knight, O. B.
Kohli, E. G.
Kroboth, A.
Landreth, T. C., Jr.
Lieffers, C. C.
Lockett, G. L.
Luchsinger, F.
Martin, V. D.

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Caracas.—Continued.
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McMillen, R. E.
McLay, J. H.
McWilliams, L. L.
Mead, H. N.
Molnar, E. G.
Moon, C. A.
Myers, L. W.
Olivieri, F. M.
Pierce, A. C.
Nelle, G. A.
Otamendi-Blanco, P. E.
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Pintea, M., Jr.
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Severson, G. A.
Shields, J. A.
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Sykes, H. J.
Taylor, D. A.
Tello B., M.
Thery-Fombona, G.
Thoms, H. W.
Tong, J. A.
Tribbey, R. J., Jr.
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Van de Putte, H. W.
Vautrin, H. P.
Vera, S. E.
Wilcox, S. W.
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Wise, M. S., Jr.
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Zaikowsky, M. W.
Caripto.—Baptista, F. G.
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Howard, D. D.
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Loeffler, R. J.
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Walla, J., Jr.
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de Laive, G. N.
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Koons, D. M.
Lethbridge, W. K.
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Matheson, N.
McCallister, E. W.
Rappaport, F. G.
van der Linden, E. J. P.
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Allred, Otis B.
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Archer, Vincent W., Jr.
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Atkinson, Ralph F.
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Austin, Kenneth O.
Autin, Octa
Avery, Don
Azim, Syed A.

B

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Braun, Lewis T.
Brazell, James E.
Brazier, Richard Meade
Breining, Edward R.
Brice, Norman Earl, Jr.
Bricmont, Arthur E.
Brierley, David A.
Brill, Willard G.
Bronte, Robert F.
Brooks, Glen D.
Brooks, R. G.
Brown, Bert O.
Brown, Chas. J., II
Brown, George G.
Brown, James S.
Brown, Kermit E.
Brown, Owen C., Jr.
Brown, Robert G.
Brown, Roger L.
Brown, William L.
Browning, John L.
Brubaker, Lewis A., Jr.
Buice, Wesley H.
Bujol, Wallace C.
Buniva, Robert
Burgher, Ballard McDougal
Burke, Robert H.
Burnell, Henry J.
Burnside, Floyd Donald
Burrell, D. D.
Bushaw, Dewey J.
Butts, Loy A.
Bynum, H. B.
Byrns, Herbert F.

C

Cable, Edwin D.
Cameron, Harriet V.
Calder, N. Bruce
Calhoun, Tom G.
Campbell, James L.
Caran, Samuel H.
Carlton, Riley V.
Cassida, Walter
Casas, Julio C., Jr.
Carey, Don W.
Carpenter, A. L.
Carroll, William R.
Carter, Gene A.
Carter, Lee S.
Carvalho, Plinio Meirelles
Causey, Edward, Jr.
Chandler, Clifford H.
Chase, Donald
Chase, Marston
Chase, Marvin C.
Chatas, Angelos Thomas
Chenot, George R.
Chesebrough, S. A.
Cheshire, Walter L.
Childers, David C.
Chisholm, Earl J.
Christensen, Robert D.
Christensen, Wesley G.
Christian, Joseph Roy
Christofferson, R. K.
Ciborowski, Edward
Clarkson, Charles F.
Cindric, Nicolas J.
Clement, James H.
Clement, Joe F.
Clevenger, Paul R.
Cloninger, James S.
Clow, Robert I.
Cobb, Alfred B., Jr.
Cobbe, James H.
Cochran, Patrick F.
Cocke, Robert R., III.
Cockrell, Robert B.
Coel, Edward John
Coleman, Carl Rodney
Coleman, George S.
Coleman, Jess B., Jr.
Collier, Lester D.
Collins, Alvah Edward
Collins, D. C., Jr.
Collins, Leo E.
Coltharp, E. Duane
Comer, Alva Gene
Comstock, Elbert E.
Cook, Lynn R., Jr.
Cook, Rufus E.
Copper, Wallace
Coppinger, John Edward
Corchary, George S.
Corliss, Earl R.
Couch, C. P.
Coulter, Kenneth C.
Covey, Jack P.
Cowles, Harold A.
Cox, Bill J.
Cox, Cameron L.
Cox, Earl J.
Cox, Eugene L.
Cox, Foy E.
Cox, J. B.
Cox, John W.
Cox, Joseph E., Jr.
Cox, William B.
Craggs, Donald E.
Cramer, Richard D.
Creamer, Arthur E.
Cretsinger, James H.
Crittendon, Bob C.
Cross, W. C.
Crossman, John C.
Cruse, John Dean
Crutchfield, John J.
Cunningham, Benjamin A.
Cunningham, Worth B., Jr.

D

Dalpini, David
Dalton, William E.
Danielson, Wesley F.
Darden, Jack M.
Davis, J. Gilbert
Davis, J. Lee
Davis, Logan E.
Davis, Richard S.
Davis, Thornton, II

Dawkins, Billy W.
De Bord, George Edward
Dechadenenedes, Jean F.
De'Geer, W. Don, Jr.
Denhollem, John W.
Denny, Billy Bruce
Denney, Charles W.
Denney, Samuel D.
Denson, Jack M.
Denton, William M.
Dereniuk, Harry
Deso, William H.
Dial, Thomas H.
Dietzel, Norman E.
Diltz, Emory Eakman
Dimon, Alfred F.
Disler, Loyd W.
Doan, David B.
Dobbs, Walter C., Jr.
Dodge, Jay R.
Donham, James F.
Doud, Lloyd C.
Douglas, Alson H.
Drake, Edward E.
Driscoll, Vance J.
Drury, Harley Frederick, Jr.
Dudley, Bill M.
Duff, James B.
Duffner, Bernard W.
Dunlap, B. H., Jr.
Dunlap, Cleo C.
Dunwoody, Joseph A.
Dupre, Sidney
DuPuy, Harvey J.
DuPuy, Marsden J.
Dye, George T.
Dye, Rayburn Lee

E

Earl, Charles L.
Eatherly, S. P.
Ebdon, James F.
Eberly, Lyle D.
Echols, A. B., Jr.
Eckard, William E.
Edgell, Wendell R.
Eggleston, Rodney P.
Eibeck, John N.
Eidt, John T.
Ek, Alvin E.
Elder, Harvey B., Jr.
El-Gazzar, Aly
Elkholi, Hassan M.
Elkin, William T.
Elledge, Joy
Ellis, Burnett E.
Ellis, David W.
Emerson, Bruce W.
Emmett, Glen E.
English, Homer C.
Enloe, Truett
Enlow, Joseph R., Jr.
Epps, Richard K.
Eskenazi, I. L.
Esmond, Thomas M.
Eubanks, Lewis B.
Evans, John R.
Evans, Kenneth D.
Evenson, Robert E.
Everett, Rex M.

F

Fain, Clement F., III
Farrell, Martin T., Jr.
Feely, Herbert W.
Feerst, Seymour
Fender, James E.
Fesmire, Carl J.
Fine, Sidney A.
Fishel, Nathan
Fitch, Ernest C., Jr.
Flores, Billy S.
Foley, Richard M.
Forbes, Walter S.
Ford, John D.
Forshag, Clarence H.
Forte, Everett L.
Foster, Jack D.
Foster, Lynn E.
Foster, Ray J.
Foster, Robert E.
Fowler, Richard L.
Fox, Fred K.
Fox, John L.
Fraunfelter, George H.
Frazier, Marshall M.
Freeland, Reese Lee, Jr.
Freeman, Billie Kenneth
Freeman, Vernon L.
Frigon, Victor S.
Fry, John H., Jr.
Fullerton, Hal B.
Fullop, Paul
Fulton, Richard H.
Funderburk, Lester

G

Gabelmann, Bill L.
Gaetano, Frank W.
Gaines, C. D., Jr.
Galli, Frank P.
Gamberg, Russell J.
Gardner, Dan L.
Gardner, Robert N.
Gardner, William Beverly, Jr.
Garrett, Marvin L., Jr.
Garrett, Pat
Garrett, Robert D.
Garrison, William H., Jr.
Garthwaite, Ivan H.
Gatchell, John H.
Gatlin, Wesley G.
Gauthier, Anatole C., Jr.
Gawarecki, Stephen J.
Gay, Robert T.
Geddie, Ralph A.
George, Jerry V.
Gerhard, Walter F.
Geyer, Alvin A.
Gilbert, Raymond E.
Gilchrist, Ralph E.
Gill, Michael William
Girner, Henry M.
Glickman, B.
Goble, James H.
Godbe, Murray C., III
Godfrey, William H.
Goin, Charles M.
Goker, Hasan
Goldberg, Jerald M.
Goodwin, Gene M.
Gorges, Donald J.
Gott, Keith E.
Graham, James R.
Graham, William J.
Gray, Lawrence F.
Green, Byron A., Jr.
Green, Chester H.
Green, J. R.
Greene, Page O.
Greenley, Richard E.
Greer, Albert R.
Gregg, Dennis E.
Gregory, Scott H.
Griffing, John W.
Grimsley, Elbert A.
Grimes, Charles O.
Grubb, Daniel R.
Guenther, Richard S., Jr.
Guerra, Arturo
Guerrero, Erasmo T.
Guidry, G. Emery
Gullixson, Richard L.

H

Haas, Robert O.
Hagler, Darrell M.
Haines, Frank S., Jr.
Hainkel, George I.
Halamicek, W. A., Jr.
Halcrow, A. F.
Hamaker, Dale E.
Hamann, Lloyd A.
Hamann, Paul M.
Hamilton, Hale
Hammer, Joseph L.
Hamon, Abraham O.
Hampton, Howard T.
Hancock, Charles W.
Hancock, Curtis
Hand, Robert J.
Hansen, B. V.
Hanson, Milfred H.
Hardwick, Charles S.
Harlan, William H., Jr.
Harmon, Robert H.
Harms, Robert A. L.
Harrell, B. J.
Harris, John Robert
Harry, Edward B., Jr.
Hart, Tom P.
Hart, Wayne D.
Hasson, Richard C.
Hatley, Allen, Jr.
Haymes, William G.
Hazenbush, George C.
Hegwer, John S.
Heid, James G.
Heilborn, George
Heins, Robert W.
Henao-Londono, Diego
Henderson, Donald L.
Henderson, James C.
Henson, Robert A.
Heppner, James P.
Herring, Seaborn C., Jr.
Herrington, James R., Jr.
Heyman, Arthur
Hicks, J. D.
Hicks, William C.
Hill, Freeman L.
Hill, Robert B.
Hill, William E.
Hilton, Edmund W., Jr.
Hinton, Charles A.
Hobbs, James P.
Hochman, Louis S.
Hodges, Basil A., Jr.
Holden, John C.
Holland, William W.
Holmes, Thomas Arthur
Holten, J. T., Jr.
Hoover, David P.
Hoppes, Marcus
Hopson, Paul S.
Horton, C. F., Jr.
Horton, Ernest H.
Hottinger, Kenneth W.
House, David M.
Houston, Robert S.
Hovel, William George, Jr.
Howard, Anthony E.
Howell, Thomas A., Jr.
Howes, Thomas Barron
Howes, Wallace A., Jr.
Huang, S. C.
Hudspeth, Robert E.
Hughes, Jim
Huling, Gerald S.
Hunt, Louis Leon
Hunt, Richard
Huntzinger, Arthur A.
Hurley, Henry L.
Huzzey, Thomas E.
Hyde, Walter E.

I

Ilgen, Grover W.
Irvin, Guy D., Jr.
Irving, Gorden E.
Isbell, Burke

J

Jacobsen, Eric C.
Jacobus, Edwin R.
James, Robert K.
Jansky, Anton E.
Jefferies, Robert L.
Jersin, Arthur J.
Jettelson, Julius
Joers, John C.
Johnson, Bernard R.
Johnson, Charles T.
Johnson, James R.
Johnson, Paul F.
Johnson, William J. A.
Johnston, Paul S.
Johnston, Robert E., Jr.
Jones, Charles H., Jr.
Jones, George L.
Jones, H. A.
Jones, Herman W.
Jones, J. Robert
Jones, Reginald J.
Joyce, James W.

K

Kanik, Stan A.
Karnes, Henry L., Jr.
Kays, William B., Jr.
Kearl, Spencer L.
Keaton, James C.
Keller, James E.
Kellogg, Nivan E.
Kendrick, Alton R.
Kendrick, Harold I.
Khayan, Mihran H.
Kidd, Harold C.
Kiester, David T.
Killingsworth, Ward W., Jr.
Kimmett, Thomas H.
Kincaid, John V.
King, Norman S.
Kinney, Paul Thomas, Jr.
Kinnie, Frank D.
Kirkpatrick, Howard M
Kitzman, A. C., Jr.
Kleiner, Abraham
Kliewer, Max Erwin
Knapp, Harold H.
Koehl, George A., Jr.
Krampert, Richard W.
Kraus, Manuel
Krieg, Joseph L.
Krog, Carl M.
Kruse, Arthur William, Jr.
Krutsinger, Virgil W.

L

Lacy, Waltus H.
Ladd, J. Bertram
Lake, William Carey
Lamb, Leslie L.
Lammers, Donald A.
Landis, Bruce A., Jr.
Landry, Allen E.
Lang, William Gerry
Lanouette, Gordon O.
Larson, Robert R.
Law, James W.
Layne, Fred A.
Leach, A. Gordon, Jr.
Lee, Russell
Lewis, Earl Frank
Libby, William A.
Linehan, Richard M.
Little, William J., Jr.
Long, Murrell D.
Looney, Hugh M.
Lopez, Luis
Love, Wallace C.
Loveless, Ernest T., Jr.
Low, Henry C.
Lowman, Quincy J., Jr.
Lucas, John H.
Lundstrom, Fred L.
Lybarger, David Dean
Lyons, Thomas R.
Lyons, Gordon E.

M

MacFarlane, James L.
MacKay, Alfred E.
Mackenzie, J. M.
Magathan, Willis J.
Malkoc, Selahaddin
Mallonee, Floyd Wesley
Manuel, Tom
Marinkovic, S. F.
Marrs, Herman G.
Marshall, Jack
Marston, Floyd L., Jr.
Martin, Clyde Douglas
Martin, W. Obier
Mason, Clyde E.
Mason, Jack A.
Mason, William E. B.
Mathews, Ronald
Mathis, William J.
Maurer, Russell B.
May, Edward J.
May, James H.
Mayer, Harold R.
Mayfield, Charles R.
Maxwell, John A.
Mefford, Nace F., Jr.
Melton, Homer D., Jr.
Meltzer, Bernard D.
Merryman, Clearence J.
Meyer, Richard F.
Michel, Russell H.
Middleton, Douglas F.
Mikkola, Jalmer T.
Miles, Frederick V.
Miles, Roy Gene
Miller, Daniel N., Jr.
Miller, Henry C., Jr.
Miller, Loyle P.
Miller, Maynard M.
Miller, Walter H., Jr.
Mills, John H.
Mims, Jim Warren
Minter, John L.
Misbeek, Robert J.
Mitchell, Harry L.
Mleak, Edward C.
Monteith, Edward E.
Moore, John O.
Moore, John P.
Moore, Ted R.
Moore, William D.
Moreland, Leonard G., Jr.
Moreno, Peter J. A.
Morgan, Jack A.
Morgan, Neil R.
Morgan, Robert M.
Morgenthaler, Charles Edward
Morlock, Robert F.
Morris, John De Witt
Morrison, Bert C.
Mosher, Warren J.
Mosley, William Norman
Mould, Richard E.
Moye, John L.
Moynihan, Cornelius S.
Mueller, Joseph P.
Mulker, Fred Robert
Murdoch, James D., Jr.
Murkve, Jerome G.
Murray, Alex S.
Myers, B. N.
Myers, William H.

Mc

McArthur, Arthur A.
McAuliffe, Henry E., Jr.
McBee, William P.
McBride, Donald S.
McClellan, Johnny B.
McColl, Deon
McCoy, Frederick Marshall
McCoy, Medford A.
McCoy, William C.
McCroden, Thomas J.
McCrone, Robert W.
McCurry, Dorrell D.
McDonnold, Stout Scott
McDuff, Lee E.
McGaw, Stewart H.
McGinness, Douglas H.
McGriff, John Patrick
McGuire, Edward M.
McKee, W. P., Jr.
McKiney, James W.
McKinzey, John L.
McKnight, Elwin D.
McMurry, J. R.
McPherson, William J.

N

Naut, Paul O.
Neal, Leslie R., Jr.
Newman, Harland E.
Nicholls, Thomas Church, III
Nicodemus, William F.
Noble, Harry A.
Noble, Robert A.
Nolan, Daniel B.
Norgren, Herbert V.
Norton, Craig R.
Nosow, Edmund
Nunn, Gordon L.
Nyun, Maung T.

O

O'Brien, George H., Jr.
OBryan, John D., Jr.
Oefelein, Francis Howard
Oliveira, Evandro H.
Olson, Charles Robert
O'Neal, Lewis
O'Neill, Donald B.
Osborne, Homer C.
Osborne, James G., Jr.
Osborne, John H., Jr.
Osburn, Edwin R.
Ostrofsky, Irving
Outlaw, Donald E.
Overly, Robert E.
Owen, J. C.
Owens, Harry B., Jr.
Owens, Jack C.

P

Pagezy, Michel J.
Pallansch, Edward P.
Pantaleo, Anthony J.
Park, David A.
Parker, Gordon A. L.
Parker, Richard Lee
Parker, William L.
Patterson, William A.
Patton, Howard L.
Paul, John O.
Paulsell, W. G.
Payne, Merrick D.
Paynter, Warren T.
Peale, Richard
Peel, Herbert L.
Perry, Ashton T.
Person, Oscar C.
Peter, Conrad W.
Peterson, Charles B.
Peterson Howard C.
Phillips, Norman D.
Phillips, Robert W.
Picard, Louis A.
Pickens, Clyde H.
Pierce, Clarence V.
Pierce, John A.
Pierson, Darrell S.

Pierson, Francis L.
Piperato, Salvatore F.
Pittman, Gardner M.
Plemmons, Othal M.
Plumley, Byron L.
Plummer, Ray N.
Pohoriles, Eugene M.
Polglase, William L.
Pomeroy, Lewis R., III
Porterfield, James C.
Poss, Alvin V.
Poth, Ralph J.
Potter, Parke McElroy
Powell, Donald O.
Powell, William H., Jr.
Prejean, Joseph S.
Preston, Floyd W.
Price, Leslie E.
Pruyn, Robert O.
Ptasynski, Harry

Q

Quesenbury, William B., Jr.

R

Rabalais, Melford F.
Rabb, Clarence Eber
Ramsey, Gerald V.
Ramsey, Patrick H.
Rankin, Porter
Rapp, Richard K.
Raslan, Nazih
Ratchen, James H.
Rathjen, David
Ray, Jack H.
Ray, Robert B.
Redmond, Merritt Kenneth
Reed, R. W.
Reigle, Gordon
Regan, William J.
Remmert, William Emil
Renberg, Kenneth
Rennie, Preston G.
Reynolds, Merrill J.
Rezak, Richard
Riccio, Joseph Frank
Richardson, Joe
Ries, Homer U.
Riggott, Harold J.
Riggs, Thomas A.
Riley, Homer G.
Rishel, Richard C.
Risien, Harvey V.
Rissmann, Kenneth L.
Ritchey, Mike A.
Roberts, Sanford M.
Robertson, James A.
Rodgers, Elton E., Jr.
Rogers, Earl Wayne
Rolston, William A., Jr.
Romer, Gus J.
Rose, Henry J.
Ross, John L.
Rowland, David A.
Rugg, Fred E.
Russell, Harold B.
Rust, Charles Warren

S

Sahankaya, Sait
Sanders, John W., Jr.
Sartin, Grover C., Jr.
Schaefer, Leo J., Jr.
Schlanger, Seymour Oscar
Schleiffarth, Donald K.
Schimmel, Glenn R., Jr.
Schneider, E. Richard
Schneider, Eugene T.
Schrenkel, Jack
Scofield, James Lamonte
Scott, Robert W.
Scury, Vincent F.
Scussel, Henry J.
See, Paul De Witt
Seipp, George F.
Shafer, Berman
Shaw, Howard W.
Shea, Jerry E.
Shead, Carleton G.
Sheats, Claud L., Jr.
Sheffield, Miller
Shepherd, James C.
Shor, George G., Jr.
Shurtliff, Darrell G.
Siekman, August E.
Siljestrom, Donald R.
Simpson, Jack
Sims, Byron Oliver, Jr.
Simms, William H., Jr.
Sinclair, Thomas G.
Sistrunk, Laurice
Six, Ivan M.
Skinner, John W., Jr.
Sledge, Albert G., Jr.
Sloan, Derral F.
Sloan, Robert D.
Sly, George, Jr.
Smart, Dolores C.
Smedley, Jack E.
Smith, Bertram L., Jr.
Smith, Gordon K.
Smith, Robert H.
Smith, Robert L.
Smith, Warren W.
Snider, Harold E.
Snider, Irving L.
Solanas, Donald Waring
Sole, William G., Jr.
Sonosky, Jerol M.
Sowers, Donald L.
Sparks, Loraine
Spaulding, James Barron
Speights, Charles Henry
Spiegel, Sidney J.
Spotts, Gerald W.
Springer, Sam E.
Spurgin, James E., Jr.
Staewen, Robert A.
Stallings, Harold O.
Stallman, Lawrence L.
Stamm, Roy P.
Stanberry, Wallace A.
Stanin, S. Anthony
Staub, Harrison L.
Stein, Russell
Steinhilber, Walter L.
Stephens, Thomas F.
Stephens, Richard G.
Sterling, Morton A.
Stevenson, Norman C.
Stieglitz, Val H., Jr.
Stockton, Robert J.
Stone, Doyle Leslie
Stone, Leo L., Jr.
Stoops, Bobby G.
Stubblefield, William L.
Sudasna, Pisoot
Sullivan, Arthur G., Jr.
Sullivan, Roland W.
Suman, Richard H.

T

Talafuse, Darwin D.
Tallard, Charles
Tankersley, Don F.
Tarr, Jack
Taylor, Fred W.
Taylor, Isaac N.
Taylor, Spencer L.
Tchillingarian, George Y.
Tenk, Lawrence O.
Terry, Joe Lee
Terry, Joe B.
Theriac, James M.
Thomas, Jim B.
Thomas, Kenneth N.
Thomas, Nelson R.
Thomasson, E. M.
Thompson, Lloyd F.
Thornton, Paul
Thorpe, John D.
Timm, Robert W.
Tonner, Richard C.
Topley, William E.
Towse, Donald F.
Tracey, James W.
Trapp, Henry, Jr.
Trice, Roy H.
Tripp, Joseph W.
Tripp, Karl R.
Trobaugh, Allen K.
Truby, Lester G., Jr.
Tsimortos, Paul
Turner, Billy J.

U

Underwood, Fleming C.
Underwood, James R., Jr.

V

Vanhorn, Harold G.
Van Lewen, Melvin C.
Van Zelfden, Gordon C.
Vaughn, George E., Jr.
Vaughn, Joseph C.
Verastegui, Pedro M.
Verret, Victor B.
Vestel, William A.
Vineyard, William Lawton
Vinturella, Sam T.
Vlack, R. C.
Voelker, Henry R., Jr.
Vogel, Alfred J.

W

Wade, Herbert N.
Wahl, Jack
Wahrhaftig, Leon
Wainwright, James A.
Walden, Everett O.
Waldrep, Jack L.
Walker, Clayton
Walker, James W. W.
Wallace, Robert R.
Walsh, Benjamin F.
Walter, J. C., Jr.
Walters, Burrell L., Jr.
Walther, Edward, Jr.
Walton, Wilfred W.
Warberg, Norman H.
Ward, H. V.
Ward, Theodore G., Jr.
Wardell, Edward B.
Wardroup, William R., Jr.
Warren, Wyman M.
Warren, John William, Jr.
Wasserburg, Gerald Jos.
Wathen, William L.
Watson, William B.
Watt, Arthur D.
Weatherly, Justin E., Jr.
Weaver, Carlton D.
Webb, Keith Thompson
Weeks, Marguerite L.
Weeks, Richard M.
Welch, William T.
Wells, William T., Jr.
Wendt, H. Edward
Werner, Harry J.
West, Jesse William
West, W. F.
Weston, Ray F.
Weyler, John R.
Wey, John E.
Whatley, James B.
Whitaker, Earl J.
White, Alvin V.
White, Paul M.
Whitlock, Edward H.
Whitman, Harold A., Jr.

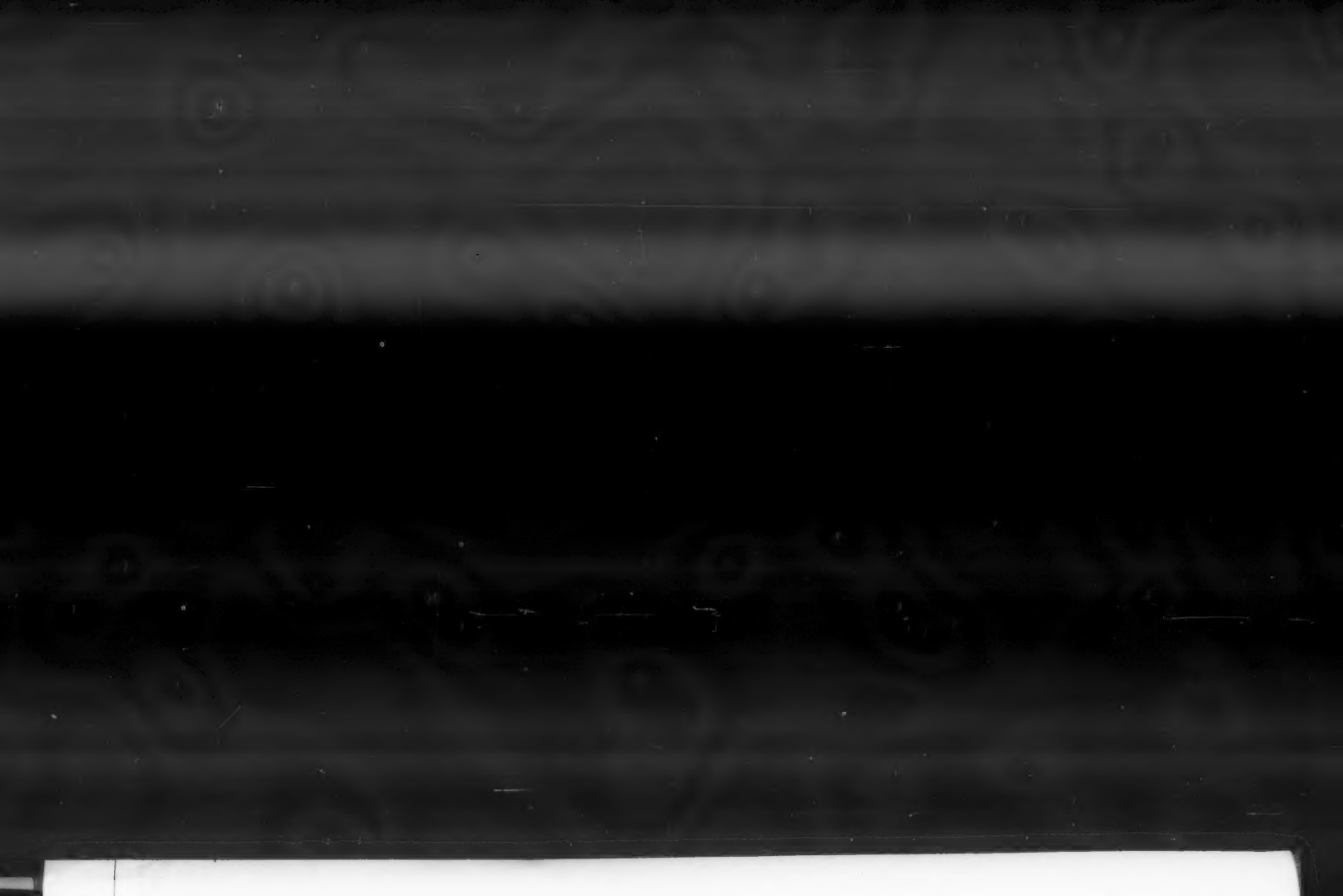
Whitney, J. W. W., Jr.
Wiberg, Lars-Erik
Wick, Harold L.
Wick, Harold L.
Widmyer, Richard H.
Wiederholdt, Ferdinand R., Jr.
Wieland, Clarence W.
Wiggin, Richard W.
Wight, John F., Jr.
Wilkie, David Blaine, Jr.
Williams, James M., Jr.
Williams, Lenford K.
Williams, Walter L.
Williams, Weldon E.
Wills, Donald Lee
Wilson, David P.
Wilson, Gerald
Wilson, Joseph D.
Wilson, Lejeune
Winn, Ralph A.
Winston, Harold S.
Winter, Claud Victor
Winters, Rayford W.
Wiseman, Blaine L.
Wishnick, John H.
Wood, Kenneth
Wood, Robert C.
Wood, William D.
Wooldridge, Clarance E.
Wright, John C.

Y

Yankee, William R.
Yee, Bing Quai
Young, Wilfred Ray

Z

Zimmerman, James R.
Zublin, Casper L.
Zwicky, Robert W.



7

JOURNAL OF

Petroleum Technology

Volume 1 JULY, 1949 Number 7

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TABLE OF CONTENTS

Petroleum Branch — Section 1

WE THE BANAUSIANS, by Hans H. Suter 5

A NOTE ON THE VALUATION OF RELATIVE PERMEABILITY, by Owen F. Thornton 7

A NOTE ON WELL CEMENTING AT LOW TEMPERATURES, by Roscoe C. Clark, Jr. 8

PRODUCTION RESEARCH — PRESENT AND FUTURE, by Morris Muskat . . . 9

NEWS OF LOCAL SECTIONS 17

Employment Notices . . . . 24 Professional Directory . . . 28

All-Institute — Section 2

BOARD OF DIRECTORS' MEETING 233

PROPOSED BYLAWS AMENDMENTS 234

RESULTS OF DUES REFERENDUM 237

MID-YEAR MEETING PLANS 238

Local Section Notes . . . 236 Student Society News . . . 240

Drift of Things . . . . . 237 News of AIME Members . . . 241

Petroleum Transactions

T.P. 2645 RESERVOIR PERFORMANCE OF A HIGH RELIEF POOL, by E. P. Burtchaell 171

T.P. 2646 PILOT GAS INJECTION — ITS CONDUCT AND CRITERIA FOR EVALUATION, by Lincoln F. Elkins and John T. Cooke . . . 180

T.P. 2640 EXPERIMENTS ON THE CAPILLARY PROPERTIES OF POROUS SOLIDS, by John C. Calhoun, Jr., Maurice Lewis, Jr., and R. C. Newman 189

T.P. 2639 FACTORS INVOLVED IN REMOVAL OF SULPHATE FROM DRILLING MUDS BY BARIUM CARBONATE, by W. E. Bergman, H. B. Fisher and P. G. Carpenter . 197

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WE THE BANAUSIANS

By Hans H. Suter
Trinidad Leaseholds, Ltd.
Point-a-Pierre, Trinidad, B. W. I.

In reply to BANAUSIA*, a geologist defends specialization by asserting that it is necessary in our petroleum powered civilization and that profit is still the driving force for both the executive committee and the foram hunter.

Banausia is on the way to becoming a best seller without the benefit of the book club. It has been read widely, and is being debated wherever the homo petrolifer sub-species of homo faber is active.

This banausian read the article with raised eyebrows and put it down with vague feeling of hypo-banausia. The implications are clear, but not all so simple as they appear—the anti-banausian dustfall covers more acres than is apparent.

One is bound to note that exploration has been singled out for a special dusting. Banausia is a challenge and is asking for an epi-banausian reply. The crowd of banausians is large, the number of "special" experts increases yearly, not only in the oil industry and the tax-gathering governments, but everywhere. Some of the vice presidents may belong here with their loyal distaff side, upon whose frail shoulders apparently falls such heavy tasks as selecting right dates, right sands, right places, etc.

The story of the extinction of the sabre-toothed tiger does not scare us in the least. We are all headed for the same destiny as the switchboard operator and the engine driver. Specialization is obviously a symptom of a developed civilization. They had the same trouble in the Palaeolithic, then in the Neolithic. It was painful enough to switch from flint to bronze, but in the end they managed it.

Banausia Without Thrombosis

Specialization does not necessarily imply arteriosclerosis senilis, specie petrolifer, with incumbent danger of thrombosis. So long as specialists are willing to play to any house and let the facts speak for themselves, specialization is not dangerous, it is a boon. Much more malignant to a civilization is its inability to change its alphabet or its system of weights and measures. Look at the Chinese painting frantic messages in ideograph, or at the Russians who were not even able to change their calendar and are 13 days (or is it 13 centuries) behind the west, and look at the splinter in our own eyes. We can't even get rid of that antiquated medieval eo-technical foot-and-inch system and that blankety blank fahrenheit.

The scientist (great addict to banausia that he is) very often is the first to change—indeed it's usually he who advocates the changes. We advocated the change from the driller's log to the electro log; who invented and insisted upon conservation, and for what purpose and with what results? To be singled out for "progressive" (or is it evolutionary regressive?) banausia in the face of the above is quite something. Manifestly, every progress, or let us say almost every progress, is the efficiency of oil exploration and exploitation has been suggested by the banausians and was adopted so often over the opposition or indifference of what we may call anti-banausians. It seems to me that on the average the impractical, dreamy-eyed, introverted banausian is more willing to change than the so-called hard-boiled, realistic, practical man, the prototype of anti-banausian, I presume.

However, to be candid there is a sore spot in this banausian world. It is lack of appreciation of the role and function of banausia and lack of proper organization and administration of it. The fault lies as much with the banausians as with the anti-banausians. The ecology and needs of that strange plant banausia moderna is simply not sufficiently understood. Then there is also the problem of one banausian encroaching upon the field of another, but this is a piece of linen which needs to be washed with a special soap.

What is the set up which will give us the benefit of banausianism without its evolutionary dangers?

It is not anti-banausia, it is simply one-over-banausia. This is not to be equated with the opposite of a banausian. This opposite is obviously a mighty, an olympian creature. He has the interest of the people at heart and never forgets the individual detail over the general perspective. The Greeks had a name for him, too. Since the species was most often found in or near a town (Polis)they aptly called him a politician. They say that the species is not unknown even today.

* BANAUSIA, by Reese H. Taylor, March, 1949, Journal of Petroleum Technology.

No, the one man wanted is perhaps not quite a politician, it is one who can rule over but need not lord it over the banausians. The best rulers are native sons. Therefore, the man over the banausians is a banausian himself.

Science Versus Tactics

The problem is to stop and prevent banausian erosion. The remedial measures are obviously to stop it at its source, canalizing the stream; to build dams, sluices, and to get a gateman. Facts must be faced. What are man-made ones, what are those of nature? What to do in a virgin territory, what in a country thrice cut over? Instead of "give me the men" it may well be "give me the territory". Then there is also that famous notion of relativity. Use methods commensurate with the task. This reminds us of the bombing operations—as the navigator tells us, "It's a waste to use celestial navigation to pinpoint a bombing target." You use it to narrow down your search area, and eventually the bombsight must take over. It would be a waste of effort and time to look through the bombsight all the way and it would be useless to ask the bombardier and his companions to guide the whole mission. One must command, guide and select; there must be a filter through which to pass the information.

It is not so much scientific method which is here involved in all these bombing missions but rather tactics. Take the field commander; he has his chief-of-staff who collects, sifts and translates the intelligence and selects the target with the help of banausian subordinates. He formulates a plan of action which is a compromise in the light of available means and not always a scientific compromise at that. Finally he comes up with a recommendation for action with calculated risks. It is he alone who sallies forth to the brass to plead with him and convince him of the soundness of the recommendation.

Don't forget the statistical relations. Every campaign brings casualties and if you fail to act for fear of casualties and if you fail to act for fear of casualties you may lose the action, and in the end the war.

In essence, the search for oil is a matter of tactics rather than of science: there is that political aspect. There may be obligations which have nothing to do with science and there is always the hurdle of limited means. In the petroleum industry we have a counterpart to the chief-of-staff and his functions are fundamentally the same, though differing in subject matter. The geologic chief-of-staff should be able to canalize the efforts of his fellow banausians with a minimum of interference from the brass. He is the logical "one-over-banausia".

This brings me to the micro-palaeontologist, that useful individual, who is said to be ever scratching the ground for bugs. It seems to me he should be congratulated for his remark about the benefits from a dry hole which he made over and above his line of duty. Wasn't he the only one who had a point of consolation? You paid 250,000 dollars for a look at a "black Golconda" and got a grey buy instead. Too bad, but what if his Plectofrondicularia leads to oil 10 miles updip?

Changing the tack ever so slightly isn't there a need or a possibility to invent, perfect and use a cheaper mechanical method of throwing the dice, making hole? Perhaps it's time for yet another banausian.

We are willing to bet one grand the present-day generation has as many pioneers as any before. Given a virgin territory they would sail right in, hobnailed like their fathers, and in a jiffy locate and test those structures visible on the surface and within easy reach of a home-made hole-master.

We The Banausians

First we heard of the profit motive. It's now a little outmoded. Both profit and the shareholder have been relegated to a back seat; in places they are even surrounded by a Spanish curtain. They will reappear, though, in the not too distant future, chastised, perhaps, but nevertheless proudly. Now the order of the day is service to the people. The service motive as incentive is an admirable, though not original, idea: unfortunately, it is too vague to be effective.

Incentives there must be, and realistic ones at that, specific, commensurate ones, or let's say incentives with "perspective". It's comparatively easy to coax an extrovert but there are some doubts that every banausian will sally forward to the call of, "Come, ye modern hewers of wood and drawers of water."

The first attention of a banausian must go to his profession, for without his profession he is no good at all. Next he must be loyal to his employer, for he gives him his daily bread. Then, and only then, can he look in perspective at that mystic personality "the people". He must and can only see the world through his own eyes.

Here we are supplying a rare elixir to the people, only to see it go up in smoke. The public, the people, are often fickle. They will switch to another elixir the moment they feel like doing so, and we the banausians often help them in this. And the thanks we get, if any, are heavier and heavier taxation. It seems that we the banausians are part of the people, too, and as such we should take an active rather than a passive attitude and sally forth to teach the people to make a more lasting use of the product of our daily effort. We should teach them to use it as raw material for something more permanent than smoke. It took nature thousands and thousands of years to form petroleum, and nature kept it for countless millions of years in store for us and here we go and blow it up in a puff.

The banausian is after professional satisfaction, after profession and scientific profit, the finding of a law of nature, the verifying of some facts on an economic and industrial scale. This once in a while results in finding oil but he is in the oil industry because it gives him just the change he wants.

The banausian's place in the oil industry is not unlike the case of the algae and the fungus which form in an ecologic symbiosis Lichen and both thrive on it and both profit from it.

Seen from a global standpoint the consequences of specialization are not so serious as yet so long as the basic education remains sufficiently broad, and there are few situations that cannot be dealt with satisfactorily by means of a responsible, federative organization and its complement the properly decentralized administration. We are all after satisfaction, we all have our incentives but everyone has his own after a fashion, all being variations of the profit or force type. So long as this is recognized we shall go forth to whatever our civilization has in store. ★ ★ ★

Technical Notes

A NOTE ON THE VALUATION OF RELATIVE PERMEABILITY

By Owen F. Thornton
The Texas Co., Houston, Texas

Recently equations have been presented by Rose and Bruce[1] and by Rose[2], showing how the relative permeability of a reservoir rock may be determined from the capillary character of the rock. In particular, equations were developed to show the relationship between capillary pressure and the effective permeability to the wetting phase in a poly-phase flow system. The equations are as follows (nomenclature the same as in the Rose and Bruce paper):

$$K = f\left(\frac{1}{k}\right)\left(\frac{\Upsilon}{P_T}\right)^2 \quad . \quad . \quad . \quad . \quad (1)$$

$$K_E = f\,S_w\left(\frac{1}{k}\right)\left(\frac{\Upsilon}{P_c}\right)^2 \quad . \quad . \quad (2)$$

$$\frac{1}{k} = \frac{1}{2}\left(\frac{L}{L_a}\right)^2 \quad . \quad . \quad . \quad . \quad (3)$$

Rose and Bruce assume that the average length of path (L_a), which the wetting fluid follows in flowing through a porous media is independent of the saturation to the wetting phase, so that $\frac{1}{k}$ is a constant dependent only on the rock, and the permeability to the wetting phase is a function of the saturation and of the capillary pressure:

$$K_w = \frac{K_E}{K} = S_w\left(\frac{P_T}{P_c}\right)^2 \quad . \quad . \quad . \quad (4)$$

In measuring the flow of electric current through partially saturated core samples, it has been observed that the electrical resistance usually is not a simple linear function of saturation. This fact indicates that the average length of path in the flow of electric current is not independent of saturation, but rather that the tortuosity of the path depends upon the average saturation to the conducting fluid as well as upon the characteristics of the rock itself. Inasmuch as the flow of fluid and the flow of electric current in many respects are analogous, it may be indicated further that the length of path for fluid also may not be independent of saturation. The following relationship can be derived to express the resistance to flow of electric current through a core sample partially saturated with conductive wetting phase, the non-wetting phase being non-conductive:

$$\frac{R_s}{R_o} = \frac{1}{S_w}\,\frac{L'_{as}}{L'_a} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where L'_{as} is the average length of path followed by the current in flowing through a length L of partially saturated core, where L'_a is the length of current path when the core is fully saturated, and where R_s and R_o are the specific resistivities of the partially saturated and saturated core sample, respectively.

It will be noted that R_o, the specific resistivity of the core sample when $S_w = 1.0$, is equal to the "formation resistivity factor"[3] multiplied by the specific resistivity of the saturating fluid.

If it be assumed that the average lengths of path for fluid flow and for the flow of electric current are the same, then equation (5) may be combined with equations (1), (2) and (3) to give the following relationship:

$$K_w = \frac{K_E}{K} = S_w\left(\frac{L'_a}{L'_{as}}\right)^2\left(\frac{P_T}{P_c}\right)^2 = \frac{1}{S_w}\left(\frac{R_o}{R_s}\right)^2\left(\frac{P_T}{P_c}\right)^2$$

The above equation suggests including a correction for tortuosity when calculating the relative permeability of a reservoir rock to a wetting phase. The correction factor may be obtained from the resistivity-saturation relationship. For instance, the following calculations are obtained for the unconsolidated sands described by Leverett[4,5]:

S_w	R_o/R_s[4]	P_T/P_c[4]	K_w (Calc.)	K_w (Obs.)[4]
0.30	0.08	0.88	0.02	0.0
0.40	0.16	0.94	0.06	0.04
0.50	0.27	0.97	0.14	0.11
0.60	0.40	0.98	0.26	0.21
0.70	0.53	0.98	0.39	0.35
0.80	0.68	0.99	0.57	0.54
0.90	0.84	0.99	0.77	0.76
1.00	1.00	1.00	1.00	1.00

It will be noted that the agreement between the calculated points and the observed data is rather good. Further investigation of the above method for obtaining relative permeabilities may be merited.

For many sands within specified ranges of saturations the following relationship has been found to hold approximately[3]:

$$\frac{R_o}{R_s} = S_w^n \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The exponent n in the above equation has been found to equal two for many sands so that equation (6) reduces to the following:

$$K_w = S_w^{n-1}\left(\frac{P_T}{P_c}\right)^2 = S_w^3\left(\frac{P_T}{P_c}\right)^2$$

The writer acknowledges the permission of The Texas Co. to submit this note for publication.

1. Walter Rose and W. A. Bruce—*Jnl. of Pet. Tech.*, Vol. 1, No. 5, p. 127 (1949).
2. Walter Rose—*Jnl. of Petr. Tech.*, Vol. 1, No. 5, p. 111 (1949).
3. G. E. Archie—*Trans.* AIME, 146, 54 (1942).
4. M. C. Leverett—*Trans.* AIME, 142, 152 (1941).
5. M. C. Leverett—*Trans.* AIME, 132, 149 (1939).

★ ★ ★

A NOTE ON WELL CEMENTING AT LOW TEMPERATURES

by

ROSCOE C. CLARK, JR.

Stanolind Oil and Gas Co., Tulsa, Okla.

In October 1945, R. F. Farris, in an AIME paper entitled *Method For Determining Minimum Waiting On Cement Time*, presented a method for calculating the minimum WOC* time required in oil well cementing operations. Briefly, this method consisted of shutting in a well, after the cement had been placed, and noting the time required for the wellhead pressure to reach a maximum. This time was then multiplied by a factor of 1.5 to determine when the cement had reached sufficient strength to support the weight of the casing.

As a result of this work, a number of areas have reduced their WOC time requirements with the subsequent saving of considerable rig time.

*WOC, abbreviation for "waiting on cement", indicates the time from when the cement is mixed to the time when sufficient strength has been obtained to allow the drilling of the plug.

The tests conducted by Farris were, for the most part, conducted under cementing temperatures in excess of 70°F. This was done because in the overwhelming majority of cases, cementing temperatures are in excess of 70°F (only in the northern part of the country, primarily in the Rocky Mountain area, in cementing surface casing are temperatures below 70°F. encountered, and such temperatures occur only during the winter months). The Stanolind Research Laboratory since that time has performed a number of tests both in the laboratory and in the field to evaluate this WOC factor when cementing temperatures are lower than 70°F. The results of these tests indicated the need for greater WOC time in areas affected by abnormally low cementing temperatures. These tests indicated that a WOC factor of 2 (Time from start to mix cement to maximum wellhead pressure x 2 = Time to drill plug) will allow sufficient time for the cement to develop adequate strength.

A field test under abnormally low cementing temperatures (surface temperature 35°F., mud discharge temperature <70°F. and cementing depth 500 ft.) in the Rangely Field, Colorado, using the WOC factor of 2, indicated the time to drill the plug as 45 hours. Well conditions preventing getting back into the well until a 48-hour WOC time had elapsed. At this time, the plug drilled firm to hard indicating that the cement had reached its final set.

It is contemplated that during next winter additional field tests will be performed to further check the results of the laboratory and field tests conducted to date. ★ ★ ★

Make Fall Meeting Reservations NOW!

Gail Moulton Nominated As Institute Director

At the June 15 meeting of the AIME Board of Directors, Gail Moulton, geologist for the Chase National Bank in New York, was nominated by the Board for the post of director at large. His tenure of office will be for three years, beginning in February, 1950.

Gail has been very active and interested in AIME affairs, and he is now serving as vice chairman of the Petroleum Branch. His biography was published in the March JOURNAL. ★ ★ ★

Were You There, Friend?

The Petroleum Branch Directory, issued June 15 was based on a card file provided from New York headquarters. In accordance with Institute policy, this card file contained only the names of members who had indicated in writing their desire to receive the JOURNAL OF PETROLEUM TECHNOLOGY, thereby meeting the administrative requirement for official classification as Petroleum Branch members.

At the date the cards were sent to us some 500 members of the AIME through oversight or misunderstanding, had not indicated which of the three monthly journals they wished to receive and so could not be assigned to any Branch. In the interval since compilation of the Directory was begun many of these members have made clear their desire to receive the JOURNAL. In order that the Directory be made as complete as possible we will print in the August JOURNAL one or more pages in the style of the Directory, which can be clipped and pasted in the Directory. This is not a perfect solution, but better, we think, than letting the matter rest on a technicality.

The basis for the supplementary pages to be printed in the August JOURNAL will be the coupon below, which should be typewritten and mailed to us before August 2. This coupon is only for the use of those members of the Institute who are receiving the JOURNAL OF PETROLEUM TECHNOLOGY and who were not listed in any manner in the Directory. It is not intended for use in effecting changes in your present Directory listing. A facsimile of the coupon may be used. ★ ★ ★

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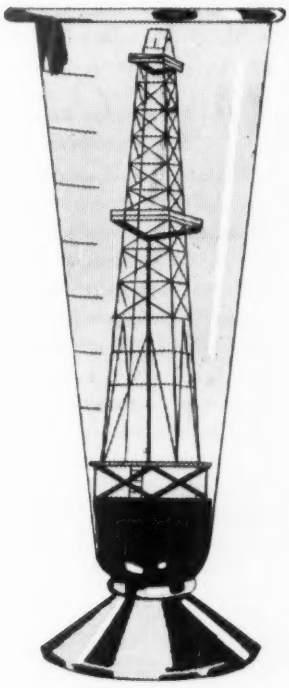
Production Research...

Present and *Future*



Morris M. Muskat

Gulf Research and Development Co.

Pittsburgh, Pennsylvania

A leading research man measures our present production know-how, looks into the future, and says a research man is born and not made.

To the extent that the title of this symposium refers to educational aspects of the petroleum industry, the present speaker is excellently qualified to say nothing. His only experience in the educational field was limited to one year of a college instructorship and two years of part-time teaching as a "teaching fellow", all more than 20 years ago. In those days there were very few petroleum engineers, as we know them now, and at that time the author hardly even knew that there existed a petroleum industry.

In discussing the subject of production research in this forum no attempt will therefore be made to outline specific curricula related thereto, or to list educational requirements. It is hoped, however, that those who are professionally engaged in the field of education will be able to draw at least some pertinent implications from a more thorough understanding of the nature and problems of production research.

To emphasize that the author possesses no pedagogical ability no definition will be given of the term "production research". And yet he must confess that on many occasions in discussions of technical subjects he has insisted on having the terms defined, as most teachers presumably would do. Why not here? Simply because a definition would probably be the most controversial and least significant aspect of the whole subject. To be somewhat more philosophical, however, we may perhaps appeal to the pragmatic and operational credo developed by the modern physicist. When you ask him what light or an electron really *is*, he feigns complete ignorance. He might even retort that even if he had any notion of an answer he would refuse to give it, because you wouldn't know what to do with it, nor would you know whether it was right or wrong. On the other hand, if he isn't too anti-social he might agree to tell you all about the observable and measurable properties of light or electrons and to describe to you how they behave under various circumstances. From that story you could make your own definitions if you cared to, provided you don't request his approval of them.

In the same manner we may sidestep the question of *defining* production research and devote our attention somewhat more profitably to a discussion of some of its varied aspects. Before entering upon this, however, we shall touch once more on the matter of terminology in a negative sense. That is, we shall exclude from the scope of our discussion matters such as drilling, drilling muds, flow string performance, well treatment, etc., which are often included among the activities of production research groups, and limit ourselves to those aspects usually described by the term, "reservoir engineering". For the latter, too, you are free to create your

Paper presented to Mineral Industry Education Division, AIME Annual Meeting, San Francisco, February 13-17, 1949.

own definition in the light of what you feel its component parts or attributes may be.

The Origin of Production Research

What have we learned from production research? And how did this come about? Let us consider the latter question first. The answer, in a word, is evolution. Production research is not a discovery. It is not an invention. It is not a mystical or abstruse theory created by a flash of genius. The production research activities of this nation today represent merely the current state of a continuously expanding and growing effort devoted to the study, from a physical and physico-chemical standpoint, of how and why oil is produced. In contrast, to some of the other industrial scientific activities the two prime movers of research — necessity and curiosity — were originally applied in the case of production research in reverse order, namely, curiosity first and necessity second. In the early days of the industry once the oil field was discovered, it required but little scientific skill and effort to produce the oil. There was no compulsion to produce efficiently, or to conserve reservoir energy. The black gold turned yellow with the greatest of ease. Research was not *needed*.

It was scientific curiosity that led to the early studies of the properties and behavior of petroleum fluids and petroleum bearing rocks. Indeed it was primarily the group of petroleum engineering pioneers of the Bureau of Mines of the twenties and their contemporary geologists in the Federal and State governments and in some of the universities who initiated these efforts. No doubt various other factors, such as the obligation to evaluate natural resources, gave support to these activities. But in the main, the origin of production research was essentially an enterprise in pure science.

It is no discredit to the oil industry that its contribution, as motivated by both current and long range necessity, followed rather than originated this field of technical effort. On the contrary, the subsequent developments by industrial research laboratories and the work they have supported or encouraged in academic institutions have amply shown that the stimulus of necessity or economic return has led to such marked progress as compares favorably with that of any pure research investigation. Indeed, the current direct expenditures for production research by the oil industry undoubtedly exceeds greatly those in university and government laboratories.

As in all sciences, the physics of oil production developed but slowly until the tools of research and basic experimental observations became available. One of the most important of these was the development of practical bottom hole pressure measuring instruments. The true reservoir pressure data that were thus recorded gave for the first time an idea of the reaction of the reservoir to production processes. The construction of bottom hole samplers permitted a determination of the gas content of reservoir crudes and their changes in volume with declines in pressure. The design of practical core barrels greatly increased the availability of samples of reservoir rocks for the study of their properties. It is these tools which made possible the growth of an understanding of what production research could and should do. And, as has been the experience in all scientific endeavors, each investigation, while answering specific questions, has raised many others requiring still further work. So, while much has been learned, the broad problem has become so enlarged that there always seems to be more yet to be done than has already been accomplished.

What Has Been Learned

It would represent a gross lack of appreciation of the accomplishments of production research to date to attempt their recounting in a few thousand words. Here we shall restrict ourselves only to brief statements of the broad features of some of the major results without any pretense of completeness. Nor will any proofs of the conclusions, either from laboratory or field evidence, be presented.

Production research has led to a gross understanding of oil producing reservoirs and of their producing mechanisms. As the result of production research we know now the physical and thermodynamic characteristics of petroleum fluids. We know how to characterize reservoir rocks quantitatively. We know the sources of oil expulsion energy. And we know in a broad sense to what extent and how these can be controlled and supplemented. Let us review these subjects briefly.

A. The Reservoir Fluids

The great majority of reservoir oils contain dissolved in them large quantities of natural gases. In many the quantity of dissolved gas is not sufficient to saturate the oil at the prevailing reservoir pressure and temperature. In these the saturation or bubble point pressure may be from a few to as much as a thousand psi below the reservoir pressure. In most cases, however, the reservoir oil is saturated at the reservoir pressure, or there is an excess of gas which overlies the oil zone as a free gas phase. For crude oils of 35° API the dissolved gas content will be of the order of 300 ft.^{3}/bbl. at a saturation pressure of 1000 psi, and will rise to approximately 850 ft.^{3}/bbl. at a saturation pressure of 3000 psi. The natural gas usually has a methane content of 50 to 98%. Except when the methane concentration exceeds 90%, the gas solubility generally increases rapidly as the pressure increases in the low pressure range, then tapers off to an approximately linear solubility-pressure relationship, and may then again begin a rapid rate of increase if the pressure-temperature conditions approach the critical state.

Associated with the gas solubility is an expansion of the crude oil. The amount of expansion is roughly proportional to the volume of dissolved gas. Conversely, as the pressure declines in a gas-saturated oil reservoir and gas is released from solution the liquid phase shrinks. The curve of reservoir oil volume vs. gas saturation pressure roughly parallels the curve of gas solubility vs. pressure. A 35° API crude will expand in volume by 20-30% if saturated with natural gas to 1000 psi, and its total expansion at a saturation of 3000 psi will be of the order of 45%. Both the gas solubility and oil expansion, at a given pressure and temperature, in-

crease with the API gravity of the crude. At a saturation pressure of 2000 psi the gas solubility in a 20° API crude will be only about 45% of that in a 40° API crude. Approximately the same comparison applies to the oil expansion volume.

Even the natural gases associated with crude oils change somewhat in composition as they are released on continuous pressure decline. Related to such composition changes the deviation in their behavior from that of perfect gases generally increases as the evolution pressure declines, reaches a maximum and then decreases again as the pressure approaches atmospheric.

An important effect of the solution of natural gas in crude oils is a reduction in their viscosity. The fall in viscosity with increasing gas saturation pressure is especially rapid in the low pressure range. At a saturation pressure of 3000 psi gas-saturated crudes will usually have viscosities of ¼ to ⅕ of the gas-free crudes at the same temperature.

The surface tensions of natural gas saturated crude oils, in equilibrium with the gas, decrease rapidly with the saturation pressure. From values of 25-28 for the gas-free crudes, the surface tension will fall to values of 8-15 dynes/cm. at gas saturation pressures of 1000 psi. At the same time the interfacial tension between the oil and water increases, though by lesser total amounts.

The petroleum fluids in condensate producing reservoirs, which are being discovered with increasing frequency as drilling depths increase, have rather unique properties from both physical and practical points of view. Because the composite reservoir fluid has a relatively low concentration of the heavy hydrocarbons, and the average molecular weight of the latter is appreciably lower than that of the corresponding crude oil components, the resultant critical temperature of the mixture is reduced so as to be less than the reservoir temperature. The critical state of a hydro-carbon mixture, it will be recalled, is the junction point, in a pressure-temperature phase diagram, of the dewpoint and bubble point curves, and at which the intensive properties of the gas and liquid phases become indentical. In condensate producing reservoirs the initial state of the reservoir fluid usually lies on the dewpoint curve to the right of the critical point. Hence, if this dewpoint gas is withdrawn from the reservoir the simultaneous reduction of pressure and temperature will lead to a liquefaction of the heavier hydrocarbon components forming the straw or colorless liquid, of 45° API or higher, termed condensate or distillate. The lighter hydrocarbons largely remain gaseous, leading to effective gas-oil ratios ranging from 10,000 to 75,000 ft.^{3}/bbl.

Within the reservoir the decline in pressure, even though at constant temperature, brings the state of the residual reservoir fluid into the two-phase region of the phase diagram. This implies a formation of liquid. Such a development of a liquid phase on pressure decline, which is the reverse of the normal type of gas-liquid phase transformation, is called retrograde condensation. Dropping out in globular form in the individual pores of the formation, this liquid phase will remain trapped in the rock, except possibly very near the well bores, while the gas is bled off and flows into the producing wells. This retrograde accumulation of liquid will increase until the pressures fall to 1000-2000 psi, after which partial revaporization develops. However, this latter process would not remove all the liquid phase even at atmospheric pressures, and the residual left at normal abandonment pressures may represent as much as 30 to 60% of the original stable condensate content of the initial reservoir fluid.

A less common, but equally interesting, type of reservoir fluid is the "liquefied gas". This is similar to the condensate reservoir fluid, but as it is deficient in the light hydrocarbons—lower gas-oil ratios—its critical temperatures exceed the reservoir temperature. On the pressure temperature phase diagram its state lies to the left of the critical point, and hence falls either on the bubblepoint curve as a saturated "liquefied gas" or above the bubblepoint curve as an undersaturated liquid. While on pressure decline such a reservoir fluid will not show a retrograde behavior, it will result in condensate type liquids with relatively high gas-oil ratio. The apparent gas solubility and oil expansion are abnormally high for such reservoir fluids, and the recovery by pressure depletion of the heavy hydrocarbons will be correspondingly low.

B. The Reservoir Rocks

From an oil production standpoint reservoir rocks have two fundamental properties, the porosity, measuring their static volumetric capacity, and the permeability, measuring the conductivity for fluid flow. Techniques have been developed for measuring accurately these properties on core samples. Productive sandstones usually have porosities ranging from 5 to 35% of the total rock volume. Productive limestones, which are often much more erratic in their void space distribution than sandstones, have porosities ranging from 4% to 30% or greater. Oil producing sandstones have permeabilities in the range of 5 to several thousand millidarcys. In dolomites and limestones the permeability is quite sensitive to lithologic structure, and may be as low as fractions of a millidarcy in massive intergranular formations, and virtually unlimited in highly fractured cavernous limestones.

Although it might now seem obvious, in view of the fact that all reservoir traps were originally filled with water, that oil bearing formations should have retained some of their original water content, this was by no means an intuitively accepted hypothesis in the early days of the industry. Indeed, it was production research which established its reality and universality. We now know that oil productive formations, producing clean oil, will generally have from 10 to 50% of the pore space filled with connate water. For strata of similar lithologic character it has been found that the connate water content generally decreases with increasing permeability, although the absolute values for a given permeability may vary over a wide range depending on the texture of the rock. Techniques have been developed for determining these fractional water saturations, their complements representing the oil saturations in the virgin rock. The analysis of cores, including measurements of their porosity, permeability and fluid content distribution, is now a routine procedure, and are

plotted vs. the depth along the well bore, so as to show at a glance the average characteristics as well as the variability of the producing section. From correlations of such data with experience and related research developments, it is often possible to predict with reasonable accuracy the nature of the production, if any, to be expected from the section cored, that is, as to whether it will be water, oil, gas, or condensate, or mixtures of these. The intervals to be perforated or opened for production for optimum performance generally can also be chosen on the basis of such data. The magnitude of the oil reserves in place can be calculated from such core analyses data, and rough estimates of the recoveries by gas drive or water drive can often be inferred from them.

As could have been expected from experience in other fields, the beautiful simplicity of Darcy's law, on which the fundamental concept of permeability was originally based, has been found to be subject to rather severe limitations. In fact, it is now known to apply only to so-called "ideal" systems, which may themselves be considered to be defined as those for which the law strictly applies. It has been learned that the requirement for its validity, namely, that the porous medium should be inert to the fluid it is carrying, is perhaps more often encountered in the form of an exception than as a valid assumption. In particular, rocks containing intergranular materials of an argillaceous nature show permeabilities to water which are frequently lower than to air by one or more orders of magnitude. Such reduction in permeability depends not only on the detailed constitution of the intergranular clays and foreign materials, but also on the ionic content and composition of the water. These findings have served to explain, in part at least, the low productivity indexes often found when so-called "dirty" sands are completed by the use of water base muds. And this, in turn, has led to the development of oil base muds for well completion under such conditions.

For inert gases themselves the simple concept of a fixed permeability has had to be abandoned. Careful experimentation here and abroad has shown that because of the extremely small pore dimensions of reservoir rocks, and especially in those of low permeability, the mean free path of the gas at moderate or low pressures may become comparable to the pore dimensions. This calls into play slippage interactions of the gas molecules with the grain surfaces, which in effect give apparently increased permeabilities to the gas. To strictly eliminate these effects it is then necessary to observe the apparent permeabilities to the gas at several mean pressures, and extrapolate the data to equivalent infinite mean pressures, where the mean free path would be negligible as compared to the pore dimensions, so as to obtain values directly characteristic of the pore geometry and comparable to those obtained when using inert liquids.

C. The Hydrodynamics of Multiphase Fluid Flow

Of more fundamental importance than these phenomena has been the recognition that the simple permeability concept, which suffices under ideal conditions to describe the flow of single phase fluids in a porous medium, must be generalized when dealing with systems simulating actual reservoir materials. In these, as has already been noted, there is always present a certain saturation of connate water. Single phase flow in a strict sense will therefore never be found in actual oil producing media. The space occupied by the connate-water will not be available to the flow of its coexisting phase of oil or gas, and hence the permeability to the latter will not be as great as if the connate water were not present. These simple observations immediately suggest that in practice the permeabilities of rocks as measured with air or an inert liquid will not directly reflect the actual fluid transmitting capacity of the same rock when acting as an oil or gas producing reservoir. And when the argument is extended further to the case when oil and gas flow simultaneously in the porous media it becomes clear that the simple homogeneous fluid permeability value loses much of its practical quantitative significance.

While these considerations showing the deficiency of the simple homogeneous fluid permeability concept when applied to actual producing systems are fundamentally quite simple, the constructive side of the question, namely, that of developing the proper means for describing the flow of multiphase fluids in porous media has been one of considerable complexity. This problem has been one of the primary objects of production research during the last twelve years, and is in no sense completely solved even yet. From a formal point of view, it developed rather early in the investigations that a description of multiphase fluid systems could be made by associating with each fluid phase separately individual permeabilities as if their respective phases were flowing simultaneously in parallel in the same porous matrix. That is, a Darcy law relationship between the volumetric fluid velocity and the pressure gradient was postulated for each phase with a permeability coefficient unique to that phase. These coefficients, in turn, gave expression to the fact that each phase was flowing in the presence of other phases by treating them as functions of the fluid saturation distribution among the phases. Obvious limitations on the total ranges in the effective permeability functions for the individual phases were that when the saturation of the particular phase was 100%, its effective permeability would become the same as for a homogeneous fluid; and for the other extreme that when the saturation for a particular phase would become vanishingly small, its permeability likewise would approach zero. Moreover, it was found convenient and physically suggestive to express these effective permeabilities as ratios to the homogeneous fluid values, such ratios being termed relative permeabilities. The above mentioned gross limitations on the corresponding relative permeability functions then implied that they lie in a range from zero to 1.

On the basis of this generalization of the permeability concept, it has been possible to construct a formal structure for the hydrodynamics of multiphase fluid flow, such as should, in principle, describe all multiphase flow phenomena including the actual performance of oil producing reservoirs. These involved two basic types of physical data other than the assumption of the validity of the generalized Darcy relationships. One refers to the thermodynamic properties of the fluid phases as expressed by the gas solubility, the expansion in volume of the oil phase due to the gas

in solution, the equation of state of the gas phase, and the viscosities of the coexisting gas and oil phases. The other is comprised of the relationship between the permeabilities of the individual phases and the saturation distribution in the pore space. The first group of data can be determined by well established techniques which have already become part of the routine procedures of laboratory p-v-t analysis. The second is still in the development stage, although it may be anticipated that satisfactory and reasonably standardized methods will become available shortly. In fact, perhaps as much production research effort has been devoted in the last several years to the perfection of techniques for determining the relation between the relative permeabilities and saturations as to any other specific phase of the general subject.

Even the earliest fundamental experiments which established the relative permeability concepts pretty well determined the broad characteristics of the permeability saturation relationship. The wetting phase has been found to fall sharply in permeability as its saturation decreased from 100%, and to follow roughly a hyperbolic curve intercepting the zero permeability or saturation axis at 25-40%. The permeability to this phase appears to be substantially independent of the nature of the other phases present, whether they be oil or gas or a combination of the two. With respect to the non-wetting phases, whether oil or gas, the behavior is somewhat different. If there is only a single non-wetting phase its permeability usually will not fall rapidly as its saturation is first decreased from 100% while being replaced by the wetting phase. However, it then falls rather sharply as its saturation is further reduced and finally vanishes completely when there is still some 5-25% of the non-wetting phase present in the porous medium. The latter quantity is termed the "equilibrium saturation", and is usually applied as such to the gas phase, although it is equally applicable from a physical point of view to a non-wetting oil phase. When both gas and oil are present as non-wetting phases the relationships are somewhat more complex, especially with respect to the oil phase, whose permeability depends both on its own absolute saturation as well as the distribution between gas and water in the residual pore space. For the gas phase, however, the permeability is rather insensitive to the distribution of the other coexisting phases, and may be considered in a first approximation as determined entirely by its own gas saturation.

While the application of these relationships to specific reservoirs requires the determination of the permeability curves for the particular reservoir rock of interest, the general physical interpretation of their broad features is of interest in itself. Thus, the rapid fall in permeability of the wetting phase, such as water, as oil or gas is first introduced into a water saturated rock, is due to the fact that at low saturations this non-wetting phase is confined primarily to the larger pores or the central parts of individual pores which provide a relatively large part of the total flow capacity of the rock. When these are occupied by the oil or gas the water is forced to move in the less conducting parts of the pore space and therefore suffers a sharp drop in mobility. Ultimately, as more of the pore space becomes occupied by oil or gas, the water is restricted entirely to the very finest pores or narrow recesses about the grain contacts, which have negligible flow capacity, and lead to a resultant water permeability that is likewise negligible or strictly zero. At the same time the exclusion of this part of the pore space from that available to the oil or gas phase does not materially reduce their permeabilities, and we find in this observation the reason why the permeability to the non-wetting phase drops only slowly as the oil or gas saturation is first reduced from 100%. At the other end of the curve of low saturation for the non-wetting phases the permeability is largely controlled by the continuity of the phase. Evidently, individual bubbles of gas or globules of oil isolated in separate pores will not flow as a stream through a porous rock without very high pressure gradients. Until the saturation of the oil or gas phase becomes so high that these individual gas bubbles or oil globules can form continuous films or channels throughout the porous medium they will have zero permeability. The equilibrium saturations in fact represent the lowest saturations of gas or oil at which continuity of the phase first develops and it can assume a non-vanishing permeability. These physical implications have an important bearing on our understanding of reservoir performance phenomena, and provide the basis for an interpretation of oil recovery mechanisms. In any case, the permeability-saturation relationship constitutes what is perhaps the most fundamental means of characterizing the dynamical properties of a porous medium when subjected to heterogeneous fluid flow.

D. Reservoir Performance

The gathering of accurate field data, such as reservoir pressures and gas-oil ratios, together with related studies of fluid flow in the laboratory, have led to a reasonably clear understanding of the gross performance characteristics of oil producing reservoirs. It is now possible to classify oil field reservoirs according to their producing mechanisms. While there may still be some differences of opinion and preferences as to the details of such classifications, the major subdivisions can be considered as fairly well established. These are (1) gas-drive reservoirs, (2) water-drive reservoirs, and (3) gravity drainage reservoirs. In practice, of course, it seldom occurs that a particular field is produced thoughout its life exclusively by any one of the mechanisms. Usually a combination of at least two and often of all three controls the actual performance, the dominating mechanism frequently being determined by the method of production.

Solution gas-drive reservoirs deriving the energy required for oil expulsion from that of the gas originally in solution in the oil generally lead to lowest oil recoveries. This is due not merely to the fact that the solution gas and its energy is limited in magnitude, but more so to the continually decreasing efficiency of the gas drive process as reservoir depletion progresses. Initially, if the producing rock has a non-vanishing equilibrium gas saturation the oil displacement efficiency is 100%, and a barrel of reservoir oil will be expelled for each barrel of reservoir gas evolved within the rock. However, as soon as gas mobility develops the displacement efficiency begins to fall, and continues

to fall due to the combined effects of increasing gas permeability and decreasing oil permeability. Ultimately the solution gas becomes exhausted and the production ceases. Depending on the detailed rock and reservoir fluid characteristics the unrecovered oil at this state of depletion may represent 50 to 85% of the initial oil content.

The gross performance histories of solution gas drive reservoirs comprise an initial period of rather slow pressure decline and low gas oil ratios, the subsequent development of high gas-oil ratios, with correspondingly steeper rates of pressure decline, and ultimately a fall in gas-oil ratio as the state of ultimate depletion is approached. The productivity indexes of the producing wells decline continuously. The reservoir pressure distributions largely reflect the degrees of local withdrawal as compared to the corresponding local initial fluid contents.

Gas injection, by replacing gas withdrawn from the producing wells retards the pressure decline. It will thereby serve to extend the flowing life of the producing wells, and retard the decline in oil mobility and shrinkage of the reservoir oil. And its passage through the reservoir rock supplements the sweeping action of the solution gas to cause additional flow of oil into the producing wells. Under favorable conditions such operations may lead to increases in total oil recovery of the order of 50% of that yielded by the solution gas drive mechanism alone.

In water drive reservoirs the oil expulsion ultimately is provided by a flushing of the oil from the pores of the rocks by the invasion of water. This process may control the whole producing history, as in the case of highly undersaturated reservoirs the pressures in which are not allowed to fall below the bubble point. In most cases, however, the immediate oil expulsion mechanism is that of solution gas drive, the invading waters serving somewhat as a scavenging agent. Under the latter conditions the reservoirs will produce under "partial" water drives, whereas if gas evolution is completely prevented "complete" water drive operation, supplemented by reservoir liquid expansion, will prevail. There is still some uncertainty as to the differences in ultimate recovery to be expected from partial and complete water drive performance. If gas is allowed to come out of solution prior to the water intrusion, the reservoir oil will suffer shrinkage and an increase in viscosity. The differential depletion in zones of different permeability will tend to accentuate channelling and bypassing of the invading waters. On the other hand, there is some evidence that the residual oil left after water flushing in a partially depleted rock may be appreciably lower than in one which is fully saturated with oil and water. Moreover, in formations which are highly variable in permeability an initial solution gas drive depletion may serve to provide at least some recovery from the tighter parts of the pay which may otherwise be completely bypassed and left entirely undepleted due to channelling of the water if the field be produced as a complete water drive reservoir.

In complete water drive reservoirs the pressures will generally decline quite rapidly at first while sufficient pressure differential is developed between the oil reservoir and supporting aquifer to induce a rate of water intrusion to balance the rate of oil withdrawals. The rate of decline will gradually taper off as production continues, and often will remain above the normal flowing pressure until the reservoir has been substantially flooded out. When the water intrusion is controlled by the compressibility expansion of the water in the aquifer the rate of pressure decline, vs. the cumulative withdrawals, will decrease as the rate of withdrawals are decreased. Within the producing reservoir the pressures will tend to be highest near the water-oil boundary and lowest in the regions remote from the edgewater. As in the case of gas-injection, water injection will tend to decrease the net withdrawal rates and thus increase the apparent effectiveness of the natural water drive.

Partial water drive reservoirs will show slower intial pressure declines. But the fall in pressure will generally continue for a longer period due to the additional reservoir withdrawals represented by the production of free gas. However, if the inherent supply capacity of the aquifer is not too limited, a balance will finally develop between the rates of fluid withdrawal and water intrusion so as to lead to substantial pressure stabilization similar to that occurring in complete water drive systems.

The recoveries from water drive reservoirs are largely controlled by the local values of oil saturation left by the water flushing process and the uniformity and continuity of the producing formation. Water drive performance generally leads to recoveries in the range of 40-80% of the initial oil content. While the lower limit here overlaps the upper limit of recoveries by gas drive, and in some cases gas drive recovery may be even more efficient than recovery by water drive, the latter does have potentialities under favorable conditions which far exceed those of the solution gas drive mechanism.

Gravity drainage is still the least well understood of the basic recovery mechanisms, though its contributions are becoming increasingly recognized. While often referred to as a gas cap expansion drive, the gas cap expansion is a rather incidental accompaniment of the physical processes involved. The gravity drainage production mechanism is indeed most easily recognized by observations of the expansion of gas caps overlying the oil body. But from a physical standpoint the gravity drainage drive is simply the process of the oil body moving down the flanks of a structure under the action of gravity. For this to take place the pressure gradients along the structural flanks must be held to a minimum, so that the regional fluid movement simulates that of free gravity fall. And to provide in this manner a gross oil flow to the downflank producing wells at rates of commercial significance the mobility to the oil phase must be high and the structure must have a substantial dip. These requirements limit the potentialities of the gravity mechanism, and make it highly rate sensitive. Nevertheless, when advantage can be taken of the gravity drainage process it offers possibilities of recovery quite comparable to that usually associated with water drives. For the oil depletion by gravity drainage will be ultimately limited only by a vanishing of its permeability, which implies such a reduction in average oil saturation as will no longer permit continuity of the oil

phase. As the breaking up of the oil into a discontinuous phase is also the basic physical limitation on the ultimate recovery by water displacement the potential recoveries by the two processes should be essentially comparable.

In addition to the general expansion of the gas cap as the oil moves downflank, which may be supplemented by countercurrent upward gas migration, the gravity drainage mechanism is characterized by a retarded growth in gas-oil ratio, as compared to the solution gas drive. If unsupported by extraneous fluid injection, the pressure will decline continuously in proportion to the total fluid withdrawals. Gas injection, however, will retard such pressure decline, prolong the flowing life, and assist in maintaining the oil mobility. As in the case of water drives, recoveries by gravity drainage should fall in the range of 40-80%.

The Future

The types of information and concepts reviewed above represent not only some of the broad accomplishments already achieved by production research, but also the major focus of attention of much of the effort which is being currently expended. Many specific projects directed toward the refinement of present techniques and the clarification of uncertain aspects of tentative or currently accepted concepts are being actively investigated throughout the research laboratories of industry and academic and government institutions. Gratifying progress is being made continuously. But what lies ahead? Only those who have never done research would be so uninhibited as to attempt predictions of the specific results of research. Here we shall merely illustrate some of the general classes of outstanding problems by reference to three rather specific examples. It is to be understood, of course, that these are not cited as the only or most important subjects for emphasis in future production research. Every research man will undoubtedly have his own preferred list of "must" projects. It is hoped, however, that the following remarks will serve to demonstrate that what we already know about oil reservoirs constitutes little more than a good beginnign in exploring a vast and difficult field of science.

Perhaps the most remarkable feature of oil reservoirs is that they stimulate so well the almost infinitesimal samples of them studied at the surface. Even before Nov. 3, 1948 the accurate prediction by Messrs. Gallup, Crosley and Roper of the views and opinions of the ninety million adult citizens of our country by samples of the order of 100,000 seemed "too good to be true." But what faith would anyone have put in them if they had based their predictions on polls of only 5 people in the country? Yet in a statistical sense such sampling would have been equivalent to the best that is available regarding the detailed rock properties in our average reservoirs when every well is completely cored! Still there is little evidence that this infinitesimal sampling leads to serious errors in the gross evaluation of oil producing reservoirs. What lies behind this amazing situation? It it purely an accident and blessing of nature?

From the pitifully few rock specimens we do obtain it is evident that microscopically all producing formations are highly variable, especially with respect to permeability. But many of the major performance characteristics of oil reservoirs can be described in at least semi-quantitative fashion by assumptions of substantial uniformity. What is the nature of the dynamical averaging processes resulting in such simplifications? Conversely, what are the detailed consequences of the inherent non-uniformity of oil bearing formations? How uniform are depletion and oil displacement processes in actual reservoirs? What control, if any, can the oil producer exercise over effects of the rock variability? These questions will not be answered soon by production research. But efforts expended in seeking these answers may well return important dividends.

A most convenient assumption which has almost universally been made by petroleum engineers is that of initial thermodynamic equilibrium within oil producing reservoirs. This has been clothed in an aura of respectibility merely by reference to the millions of years which geology indicates to be the age of oil bearing accumulations. In terms of chemical and physical reaction rate processes studied at the surface, it seems indeed intuitively certain that all reservoir fluid properties must have reached complete thermodynamic equilibrium during the millions of years of burial of the reservoirs. Yet what is the explanation of observed variations of 20 degrees in API gravities of crudes over several hundred feet of elevation within individual continuous geologic strata? Obviously, such systems are *not* in static thermodynamic equilibrium. Does this imply the persistence of chemical transformation processes within the reservoir rocks after accumulation at rates exceeding those of diffusion and equilibration? Does the tremendous surface area to which reservoir oils are exposed, and indeed the geologic periods of exposure, suffice perhaps to provide sufficient cumulative catalytic reactivity, even at the low reaction temperatures, to result in net composition changes overbalancing the homogenizing transport processes? And how is one to reconcile with equilibrium concepts reports of gas undersaturation along the flanks of structures which initially contained free gas caps? Or large variations in original bubble points — exceeding the effects of local pressure, temperature and crude gravity variations — within the same undersaturated reservoir? What effect will such non-equilibrium phenomena have on reservoir performance?

Is equilibrium to be assumed during producing operations? There is indeed considerable laboratory and field evidence that to a good approximation phase interactions do occur under equilibrium conditions in many instances. But it also can be readily demonstrated that under certain conditions the pressures on gas-saturated liquids can be reduced without the instantaneous evolution of gas and development of equilibrium phase distributions. Is the assumption of continuous equilibrium, which does have the plausibility of simplicity, represent merely a thin veil for hiding intellectual inertia? It would be well to devote some research effort toward establishing what role, if any, non-equilibrium processes play in reservoir exploitation.

Our brief references to production mechanisms undoubtedly reflect correctly the gross features of the physical processes involved. But the miscroscopic aspects of the problem are in no

sense thoroughly understood. Are capillary pressure phenomena investigated under static conditions quantitatively applicable to the dynamic processes occuring during oil production? Are gas-liquid dynamical interactions studied at normal pressures and temperatures with surface tensions of 30 dynes/cm. applicable to reservoir conditions where the surface tensions may be less than 5 dynes/cm? What role will hysteresis effects in permeability-saturation relationships play in oil expulsion mechanisms? Does the same differential wettability between the oil and water phases apply to the whole of the grain structure of a reservoir rock and also to intergranular fines? What is the microscopic dynamics of the displacement of oil by water? Is it rate sensitive? Is there simultaneous flow of oil and water in individual pores behind an advancing water front?

Who will claim certain knowledge of the answers to these questions and many more like them? Why bother to look for the answers? Because it is fun to try to satisfy scientific curiosity. But to those who have to finance such research a much more pragmatic reason can be offered. By applying what we already know we must anticipate leaving unrecovered in most reservoirs an amount of oil at least half as great as that which we shall recover. But even if only 1% of these irrecoverable "reserves" were made available to recovery economically our supplies would be increased by at least 100,000,000 bbls. It is evidently worth gambling substantial research effort on the possibility of acquiring a $250,000,000 asset. Of course, it is conceivable that in spite of our limited knowledge of all the details of reservoir dynamics our engineering production practices already suffice to develop the absolute maximum of oil recovery. And undoubtedly we can dismiss at once any grandiose illusions that research will ever lead to practical methods for recovering literally 100% of our oil reserves. Nevertheless, it would seem to be no less than a brazen denial of the historical facts of scores of years of scientific endeavor to proclaim at this state of infancy of the science of oil reservoir phenomena that practical perfection has already been achieved. Indeed it is not so much faith in research that is needed to justify further production research effort, but rather a clear understanding of our state of ignorance. We have good reason to be proud of our accomplishments to date. But if what we still don't know about the physics of oil production has no practical bearing whatever on the efficiency of oil recovery, the science of reservoir engineering when fully developed will undoubtedly encompass a greater mass of useless information than encumbers any field of engineering or technology.

Education for Production Research

Recalling again the title of this symposium, it may be well to conclude with some comments on the educational aspects of the subject. These may fit in well with our opening remarks in confirming the embarrassing ignorance of the author with respect to problems of education. How does one become educated to do production research? The answer, in my opinion, is that one does not become "educated" to do production research or any other kind of research. Research men are the products of physiological rather than pedagogical processes. They are specimens of the human race possessing mental attributes which are uniquely suited to research activities, and probably undesirable for many other respectable purposes. They are a breed afflicted with insatiable curiosity. They are incorrigible skeptics. They insist on confessing —at least to themselves—vast ignorance. Yet they have confidence in their ability to remove at least small bits of the iron curtain shielding the universe of the unknown. And they like to keep on attacking this iron curtain even when told that it is made of armor plate.

Where does education fit into this picture? It is the responsibility of educational institutions first to recognize among their students those who have the mental temperament required for research. Secondly, it is their duty to take these unique specimens in hand, guide them, encourage them, inspire them, and give them the educational tools and background necessary for beginning their researches at the forefront of the science they are to explore.

Research is the process of advancing the current state of knowledge. Potential production research men must be given the fundamental backgrounds of the sciences as the primary prerequisite of their education. Physics, chemistry, geology, and mathematics will be their indispensable tools. One who is to engage in production research must not be allowed to enter on his career burdened with the handicap of a deficiency in any of his basic weapons of attack. He does not need to become saturated with masses of uncorrelated and descriptive facts. But he must be trained so as to thoroughly understand—without equivocation—the principles, processes, and symbolic representations of the laws and phenomena of nature. Specialized course work aids in defining the gross objectives of a particular field of science. Yet it will be largely wasted effort if it is not based on the solid foundation of the elementary principles of the sciences. It is desirable to bring the student "up-to-date" on the current factual status of his science. However, it is more important for the student to learn the methods by which the subject has been advanced in the past, the general principles that have been developed, and to get experience in locating available information and data.

Finally, the students' instructors must possess enough intellectual character not only to admit but to point out the limitations of the state of knowledge of the subject, even though this may be misinterpreted as reflecting a purely personal deficiency. The student must be encouraged to ask embarrassing questions, and be inspired to go out and try to develop the answers himself. The antidote to the admission of ignorance is not a pretense that the answer if known would be unimportant. Rather it is the stimulation of a challenge to lift the veil of ignorance as a personal or collective accomplishment.

Curricula and planned course programs are a necessary part of the mechanics of education. They are the fill-in matrix of the structure of organized training. As means for preparing for production research the most vital part of this structure is the integrated and fused framework of basic knowledge common to all the engineering professions, and the intellectual atmosphere which provides its environment.

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Pacific Petroleum Chapter Activities

By Frank Parker

The Pacific Petroleum Chapter and Junior Group joined to hold a field trip to Oakridge Anticline and Ojai, Friday, June 17, with 130 members and guests attending. An invitation was extended to the Pacific Section of A.A.P.G. to participate.

The trip was embellished by a lunch at Shiells Canyon and a thick steak barbecue in the evening at Dennison Park in Upper Ojai Valley. Oscar Estill, Division Electrician, General Pet. Corp., Ventura, and his crew, William Alexander, Ev Osmond and William Humphrey, also of General Petroleum, volunteered to prepare the steaks according to the secret formula of Chef Oscar.

The technical program included a description of the general geology of the region by guest speaker Elmer Baddley of The Texas Co., descriptions of field operations at Shiells Canyon and South Mountain by Fred Maloney of The Texas Co., at Bardsdale by Albert F. Woodward and Milan Arthur of Union Oil Co., at South Mountain Extension by Ed Lesperance with F. E. Fairfield, Opr., at West Mountain by "King" Kohle of Los Nietos Co. and at Ojai by Irving T. Schwade and Karl Krieger of Richfield Oil Corp. The information presented, most of it not available in publications, was too copious to be reported here, but those present who took full notes are now equipped with an authoritative guide book for the region. Maps of the trip and fields were furnished through the courtesy of Rapid Blue Print Co. of Los Angeles.

The smooth running of the trip and the excellent array of speaking talent is a tribute to the planning and hard work of the local field trip committee headed by Ted Mitchell of Shell Oil Co., and assisted by Irving T. Schwade, Richfield Oil Co., John Curran, General Pet. Corp., Watson Lupton and Bob McEntee, Shell Oil Co., and Leo Moir, Wilshire Oil Co. The credit for selecting such a capable group goes to Lowry Wadsworth, Field Trip Chairman of the Chapter. Assisting at the barbecue was "Mac" McKenzie in charge of serving and Charles T. McClure in charge of clean up.

The liberal refreshments were donated by Baroid Sales Division of National Lead Co., Eastman Oil Well Survey Co., Lane-Wells Co., McCullough Tool Co., Pacific Perforating Co. and Schlumberger Oil Well Surveying Corp.

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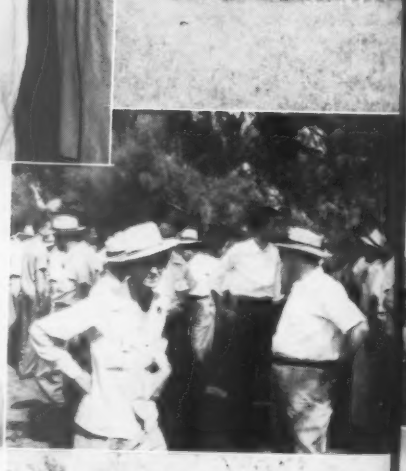
Above, Lowery Wadsworth, General Pet. Corp., Los Angeles. Wadsworth was Field Trip Chairman in charge of the Oak Ridge Anticline and Ojai Field Trip.

Below, J. F. Alexander, F. B. Webb, and W. S. Allen, all of Lane-Wells Co., are having lunch in Shiells Canyon.

Below, Albert F. Woodward describes Bardsdale Field. Right, a copy of the announcement that was mailed to the members.



Southwest Texas Section Activities

By Raymond Keller, Jr.

June 4 was a banner day in the Section. For the last meeting before the summer period, 161 members and guests enjoyed an afternoon tour through some of the major operations of the King Ranch, a well-known cattle producer in Southwest Texas. Following the tour, 243 persons concluded the afternoon by attending a barbecue at the Humble Stratton Camp near Kingsville, Texas, site of the ranch headquarters.

J. K. Northway, chief veterinarian for the ranch (picture 1 above), conducted the tour, which began with an hour lecture in the auditorium of Texas Arts & Industries College in Kingsville. The main topic discussed by Northway was how the ranch pioneered and developed the Santa Gertrudis breed of cattle, which is the principal breed now grown there. It was started in 1917 by cross breeding the Brahman (zebu) and Shorthorn types in order to produce a meat-bearing animal that could exist efficiently in the semi-arid ranching country in Southwest Texas. This experiment was successful, and all of the Santa Gertrudis cattle now on the ranch descended from it. The breed is slightly larger than ordinary cattle, and grows heavier on grass feeding than any other.

After the lecture Northway conducted the group through some of the pastures adjacent to the ranch headquarters, explaining the practices of soil conservation as well as cattle breeding carried out there. A high point in this tour was a visit to one of the stock pens where a group of Santa Gertrudis steers that have been on feed for four years are kept. This is an experiment which has produced steers weighing an average of 2,500 lbs. each (picture 2 above). One slaughtered recently weighed 2,700 lbs. — he was so large that the usual ranch transporting equipment would not accommodate him, and he had to be butchered on the ranch.

Other points of interest were: The stallion barns, where the chief attraction was Bold Venture, sire of Assault and Miss Princess (picture 3 above); a herd of pure-bred Brahmans (4 below); the quarter horses which are especially bred for cattle working (Northway believes the instinct to herd cattle can be bred into horses as pointing is in dogs) (5 below); and the racing horses (6 below).

The ranch was started in the early eighteen-fifties by Captain Richard King, with the purchase of 54,000 acres along Santa Gertrudis creek. It has expanded and contracted in holdings, but now contains slightly less than one million acres which are operated in four separate divisions. It is considered to be one of the largest single oil reserves in the U. S.

In addition to Northway, Frank H. Dotterweich, director of the division of engineering of Texas A & I College helped to guide the tour, and Al Kleberg, business manager of the King Ranch, served as co-host. They are shown in the center of the left page. Reading left to right are: Raoul Bethancourt, Section chairman; Robert C. Eckhardt, secretary of Texas A & I; William H. Strang, secretary of the Petroleum Branch; Kleberg and Dotterweich. ★ ★ ★

Oklahoma City Section Activities

By Harold Sells

The last meeting until fall of the Oklahoma City Local Section was held Wednesday, May 18, at the Biltmore Hotel, Oklahoma City. In the absence of the chairman, the meeting was conducted by first vice-chairman Henry Waszkowski, Oklahoma division engineer for Magnolia Pet. Co. After considerable debate, the presiding officer decided to mention an API barbecue to be held the following week.

The lecture of the evening was presented by Alex W. Francis, assistant chief engineer of National Tank Co., Tulsa. Francis was assisted by Lynn Burrus, National Tank Co., Oklahoma City. The lecture, entitled "Stage Separation", proved to be interesting and informative, since the material and field data has never been published. The lecture was copiously illustrated by slides, one series of which is shown on this page.

As defined by Francis, stage separation, as applied to oil production, is a process in which the oil and gas mixtures, flowing from producing wells, are separated into liquid and vapor phases by two or more equilibrium flashes at consecutively lower pressures. The ideal method of separation to retain the maximum amount of fluid flowing from an oil well would be that of true differential liberation of the gas by a steady decrease in pressure from that existing at the well head to the atmospheric, or near atmospheric, pressure maintained in the storage tanks. To carry out such differential process would be impractical. A very close approach, however, towards differential liberation of gas can be accomplished by putting the mixture of oil and gas through several series connected separators, in each of which flash vaporization takes place. In this way the maximum economical amount of liquid flowing from the well can be retained as crude oil in the stock tanks. The application of the process of stage separation offers to the oil producer a long neglected means of increasing revenue from property now in operation.

Alex W. Francis, assistant chief engineer of National Tank Co. in Tulsa, who spoke on "Stage Separation" at the May 18 meeting.

In order to illustrate the effect of separation pressure and the number of stages on oil recovery, gasoline recovery, and gross operating revenue, curves developed from field tests on several types of crude were presented. In view of limited space, only one series of these curves accompanies this article. Curves 6 through 10 were prepared from data obtained on a study of crude oil production of 44° to 47° API gravity having a gas-oil ratio of 1,000-1,200 cu. ft. per barrel.

For purposes of clarification two-stage separation was defined as that type of operation obtained when one oil and gas separator is used in conjunction with storage tanks. Three-stage separation involves the use of two oil and gas separators and storage tanks. The storage tanks are classified as a stage of separation because oil and gas do separate in these vessels.

So that direct and quantitative comparisons could be made for various separator conditions the oil recovery, gasoline recovery, and gross operating revenue curves were plotted on a basis of the yield from 100 barrels of reservoir fluid. In explanation it should be noted that 1,000 barrels of reservoir fluid has been constructed as being that quantity of free gas, solution gas, and oil which occupies void space in the reservoir equivalent to 1,000 barrels (5,615 cu. ft.) under reservoir conditions.

As compared to the data on the lower gravity crude, the data on 44° to 47° API gravity crude involves higher first separator pressures. Generally speaking, optimum separator conditions are reached at higher pressures for the higher gravity crude. The zone of greatest oil recovery, as shown on Curve 6, occurs with three-stage separation with an intial separator pressure of approximately 750 psia.

A condition of major importance in operating a separator, or separators, for the maximum benefit to the producer should be emphasized with reference to Curve 6. This involves the bad practice of operating one oil and gas separator

Lynn Burrus of National Tank Co. in Tulsa assisted Francis with the presentation of "Stage Separation".

at high pressures which are beyond the optimum for two-stage separation. The optimum for two-stage operation occurs in the region of 125 psia for 44°-47° API gravity with gas-oil ratios of 1,000-1,200.

Curve 7 indicates the influence of separator pressure and the number of stages on the gravity of the oil in the stock tanks. Since this type of production yields oil above 40° for all operations and no price increases result from gravity increase, the information has minor importance in this instance. Curves 8 and 9 indicate the influence of separation pressure and the number of stages on the natural gasoline recovery and the value of that gasoline to the producer. As would be expected, as operating pressures are increased to put more liquids in storage tanks the gasoline recovered from vent gases from the separator, or separators, must likewise decrease. This condition is reflected in Curve 8. More natural gasoline is recovered from three-stage operation than from two-stage operation *at a common initial separator pressure condition*, since for the purpose of comparison it has been construed that all vent gases from the separators will be delivered to the gasoline plant for extraction, and that the volume and g.p.m. of each vent gas will be determined separately.

The total gross value of the oil and gasoline recovered per 1,000 barrels of reservoir fluid, as reflected by separation pressure and the number of stages, is indicated in Curve 10. Under current price conditions, an operation involving two-stage spearation with the oil and gas separator operating at 50 psia would give a total gross value of approximately $1,170 per 1,000 barrels of reservoir fluid. By employing three-stage operation and an initial separator pressure of 750 psia, the gross value of operations would be increased to $1,200 per 1,000 barrels of reservoir fluid. Also, contrary to general belief, this increase in gross operating value is more marked, in many instances, when lower gravity crude is considered.

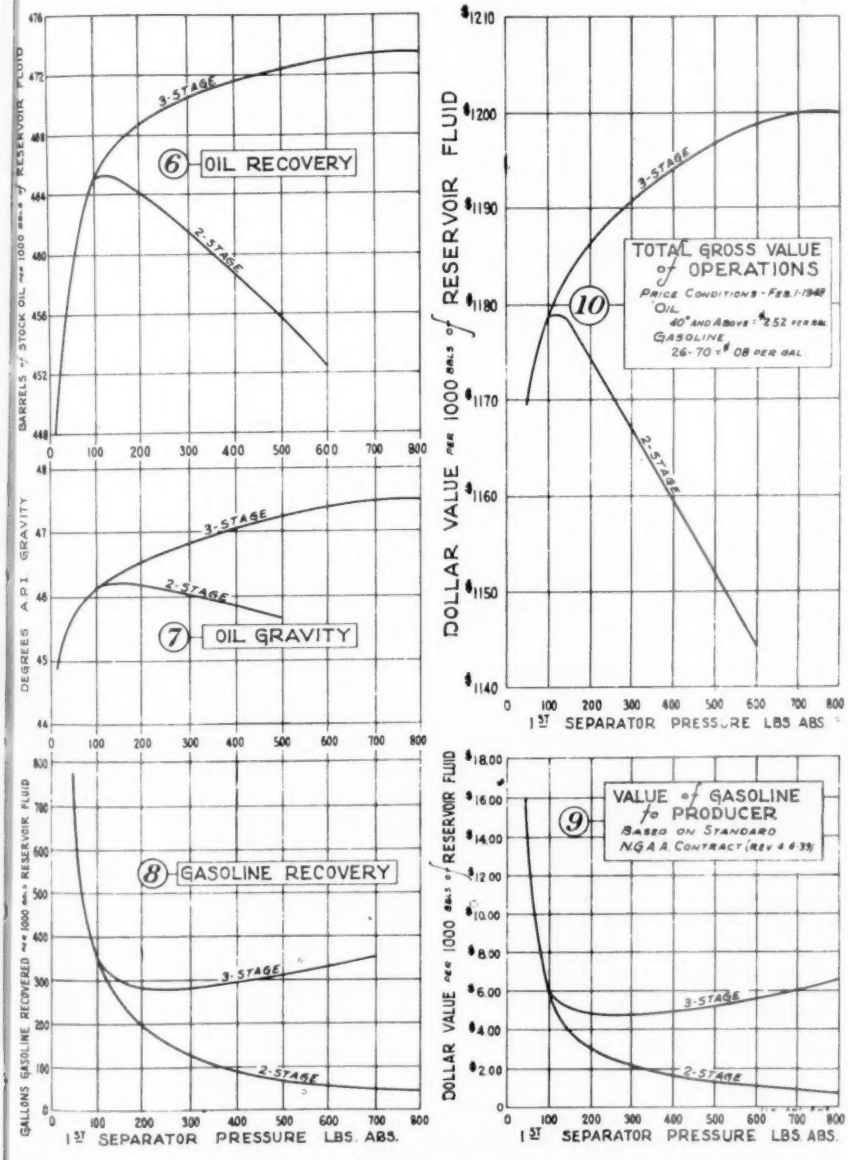

6 OIL RECOVERY
BARRELS OF STOCK OIL PER 1000 BBLS OF RESERVOIR FLUID
3-STAGE
2-STAGE
7 OIL GRAVITY
DEGREES A.P.I. GRAVITY
8 GASOLINE RECOVERY
GALLONS GASOLINE RECOVERED PER 1000 BBLS RESERVOIR FLUID
1ST SEPARATOR PRESSURE LBS. ABS.
10 TOTAL GROSS VALUE of OPERATIONS
PRICE CONDITIONS - FEB. 1, 1949
OIL
40° AND ABOVE - $2.52 PER BBL
GASOLINE
26-70 ° - .08 PER GAL
DOLLAR VALUE PER 1000 BBLS of RESERVOIR FLUID
9 VALUE of GASOLINE to PRODUCER
BASED ON STANDARD
NGAA CONTRACT (REV. 4-4-38)

Fig. 1 — Effect of separation pressure and number of stages on oil recovery, gasoline recovery and gross operating revenue; 44° to 47.5° gravity; gas-oil ratio 1,000 to 1,200.

Personals

MARVIN REMPKE and BILL BUCK, division reservoir engineer and district superintendent for Phillips Pet. Co., cornered the doubles championship in the Oklahoma City Bowling Tournament recently to demonstrate that engineers can be proficient in activities other than slipping slide rules and producing oil. They rolled up a total count of 1,378, the highest score ever rolled in the history of the Oklahoma City tournament.

J. M. GIBSON, petroleum engineer with Sohio Pet. Co. and formerly located at the West Edmond Hunton Lime Unit, has been transferred to Russell, Kansas.

CLARENCE M. NETHERLANDS, graduate of Bish-Mathis Institute, Monroe, La. and Tulsa Univ., will enter the employ of Sohio Pet. Co., gas-gasoline section, in August. He has previously worked for Weaks Supply Co. and for Interstate Gas Co. ★ ★ ★

ALTON B. COOK

JOHN A. MURPHY

GLENN M. STEARNS

WILLIAM L. HORNER

Mid Continent Section Activities

By Jack H. Beesley

The last meeting for the spring season was held on May 31. John P. Hammond, retiring chairman, was presented with a gold tie clasp to which was attached a standard blue and gold AIME members' charm as an expression of appreciation for his administration of Section affairs. It was engraved with his initials and "Chairman, 1949, Tulsa, Okla."

Three new members were elected to the Executive Committee of the Section. They are shown above, left to right: Alton B. Cook, petroleum engineer, U. S. Bureau of Mines, Bartlesville; John A. Murphy, petroleum engineer, Continental Oil Co., Ponca City; and Glenn M. Stearns, development supt., Stanolind Oil & Gas Co., Tulsa. Also on the committee are William L. Horner, chief engineer, Barnsdall Oil Co., Tulsa, shown at left, and William H. Burke of Tulsa, not shown.

Return of Surplus Journals Requested

The popularity of the JOURNAL OF PETROLEUM TECHNOLOGY has been greater than our expectations, and our stock of some back issues has been depleted. This would serve only as an attest to its popularity except for another consideration that is involved. When anyone joins AIME during a calendar year, the by-laws provide that he will receive all of the issues, for that year, of the monthly journal he elects to receive. Since some issues are out of stock now, because of the unanticipated demand, the Institute cannot now comply with the by-laws and provide all back issues of the JOURNAL.

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The Editor.

North Texas Section Activities

By Kenneth F. Anderson

The May meeting, which was scheduled for the last meeting before the summer vacation and then cancelled because of the flood in Fort Worth, was rescheduled for June 13 and the same speaker, John Campbell, Lane Wells Co., gave an excellent talk to a group of 75 members and visitors. The meeting was called to order by Chairman Don Harlan and a short discussion of Sectional affairs ensued. In accordance with a motion passed at the last meeting, Harlan announced the appointment of a five-man committee which is to investigate the success of study groups and special meetings that have been held in the past by other sections of the AIME, and to make recommendations regarding the advisability of having a greater number of meetings per year, particularly at Dallas, than has been the custom in the past. The members appointed to serve on this committee are Gordon Fisher, Fort Worth; Charles B. Carpenter, Dallas; Henry J. Gruy, Dallas; Paul C. Dean, Fort Worth; and Benson M. Kingston, Breckenridge, Texas. Fisher will act as chairman.

Patrick Reardon introduced Campbell who discussed radioactivity well logging before the Section. The address which dealt both with the theory and interpretation of radioactivity well logs is summarized as follows:

The gamma ray and neutron curves are similar, although not the same, to the potential and resistivity curves of an electrical log. The conditions under which they may be run, however, are different, i.e., satisfactory radioactive logs may be obtained inside casing or in any kind of well fluid.

The radioactive well log plots two curves and they are identified as the gamma ray curve, which indicates the relative intensity of gamma ray emissions; and the neutron curve, which is a measure of the relative presence of hydrogen ions, or fluid content. Since all rocks emit gamma rays in varying amounts, the gamma ray curve is useful in determining lithology and correlating sub-surface strata. The most important use of the neutron curve is to indicate fluid in any given formation; in order to be interpreted, however, it must be used in conjunction with the gamma ray curve. Minor fluctuations of the neutron curve represent changes in sedimentary conditions and may be applied to reservoir analyses on productivity.

Sands, dolomites, and limestones, are recorded on the gamma ray curve as low values to the left because they lack radioactive material, and shales record to the right. The gamma ray curve has no base line but the neutron curve has a shale base line caused by the great hydrogen density of the shale. This causes the neutron curve in sandstone and limestone formations to fall to the right of the shale.

John L. P. Campbell of Lane Wells Co. in Houston spoke on "Interpretation of Radioactivity Logs in the Limestone Reservoirs of North and West Texas" at the July 13 meeting in Fort Worth. He is a native of Pennsylvania and a graduate of Cornell in geology in 1935. After four years with Cities Service, a year with Seaboard, and a year with Well Surveys Co., he joined Lane-Wells in 1949 when they leased the gamma ray tool. He is now Gulf Coast Division geologist for that company.

Radioactivity logs in North Central and West Texas have proved effective because the limestones and dolomites in these areas contain fluid as interpreted from the neutron curves. Records show that in this area additional production has been found in upper formations in several wells from which cores, drillers' samples, and other types of information were lacking.

Because of the inaccuracy frequently occurring in depth measurements resulting from drilling time lag, lost core recovery, pipe measurements, and phys-

Continued on Page 24

An unusual feature in some Sections, but not in North Texas, is women members. Miss Margaret E. C. Keiles, left, assistant chemist, and Miss Adele Chambers, right, junior chemical technician, with Atlantic Ref. Co. Laboratories in Dallas, are both members and attend meetings regularly.

J. A. Moore, left, and H. G. Freedman, both with Continental Oil Co. in Wichita Falls, attended the June 13 meeting from that city.

Members and guests at the speaker's table for the June 9 meeting. Left to right are P. H. Gardett, W. F. Cerini, A. F. Woodward, L. W. Chasteen, I. A. Marshall, Jr., N. B. Clark, V. Robinson, and F. S. Parker.

Pacific Junior Group Activities

By I. A. Marshall

On June 9 the Junior Section of the Pacific Petroleum Chapter met at the Rio Hondo Country Club in Downey, California. In the absence of Chairman C. T. McClure, Norman B. Clark opened the meeting and introduced the speaker, Verne Robinson.

Robinson began by describing the primary constituants of an oil and gas lease. He discussed the latest court decisions involving hold-out lessors in community leases, the surface and subsurface rights of both lessor and lessee, and the inclusion of clauses allowing the lessee to inject water or gas as a secondary recovery method. Robinson cited many cases of law involving controversy over oil and gas leases, pointing out the advisability of the lessor and lessee consulting an attorney in order to be sure that the wording of the lease leaves no doubt as to its exact meaning.

He pointed out that it is particularly important to define clauses covering "paying quantities" of oil and gas, drilling depth requirements, multiple zone development, and offset obligations. He emphasized the advisability of the lessee familiarizing himself with tax law before making a lease. In connection with this subject, he stated that the 27½% depletion allowance cannot exceed 50% of the operator's yearly net profit for tax purposes.

In conclusion, Mr. Robinson reviewed several trial decisions dealing with oil and gas leases and answered questions from the audience. ★ ★ ★

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 601 Continental Bldg., Dallas 1. When applying for a position, give complete qualifications in first letter, and show return address on envelope. These replies will be forwarded unopened, and no fees are involved. Any answer will come directly from the firm listing the job.

Replies to the position below which is coded Y2218C should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

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♦ Petroleum geologist, 24 years old, two and one-half years' experience in Peru, surface geology and photo interpretation. Degree in geology, Harvard University. Available for domestic or foreign work. Code 106. ★ ★ ★

North Texas Section

Continued from Page 23

ical hole conditions, measurements by radioactivity well logging tieing in with casing collars is a most important application. Two valuable uses for the gamma ray curve are the location of radioactive solutions such as an oleate to determine porosity and permeability versus porosity without permeability, and carnotite as a tracer in cement or plastic to determine vertical and mass travel on a squeeze job.

There are now nineteen known and applied uses for the radioactivity survey. Of these, the greatest use is to settle differences in measurement. A second group of surveys may be itemized as: locating cased-off oil and gas zones; plug-back operations to eliminate bottom hole water; tracer travels; and particular field problems where engineering, geological and production practices have a direct bearing upon the completion or recompletion of a well. ★ ★ ★

Permian Basin Section Activities

By Tom W. Flewharty

H. D. Murray of Midland, district petroleum engineer with The Texas Co., spoke on the subject of "Selection and Maintenance of Lease Production Tanks in Sulphide Areas," to approximately 100 members and visitors attending the Permian Basin Section's meeting in Midland's Hotel Scharbauer on May 16.

Prepared discussions on the same topic were given by Jack Hamilton of Crane, Gulf Oil Co.; Ken Williams of Odessa, Shell Oil Co.; Ike Lovelady of Odessa, Sivalls Tanks, Inc.; and Bill Moore of Midland, Humble Oil & Ref. Co.

The meeting was opened with a short business session during which Tom C. Frick, section chairman, recommended a motion amending the by-laws so that officers of the section might be elected in December rather than in January be brought forth. The motion was moved, seconded and carried unanimously.

William N. Little, program chairman, then introduced the speaker. A summary of Murray's paper follows:

Just as it became necessary to set a standard unit of measure for crude oil, it also became necessary to standardize the type of vessels used to store the fluid. The American Petroleum Institute has set up standards of material and fabrication or construction. Although these standards are revised from time to time to maintain the highest level of efficiency, there are some questions which cannot be answered by any set of standards, and many of these questions are encountered in the Permian Basin Area and those similar to it.

Selecting lease production tanks or other storage equipment for use in the Permian Basin Area presents possibly more problems than in any other one area. Practically all of the production from this area contains hydrogen sulphide, and a large percentage is accompanied by salt and sulphur water production, both of which are contributory to extreme corrosion conditions. In addition, much of the water contains scale forming elements.

In all areas, however, factors that should be considered in the selection of tanks and treaters are production rates, water production, conservation, corrosion resistance, salvage value, operators' standards and policies, changes in design, and cost per unit.

In the development of materials and design affecting selection and maintenance, various types of metals and coatings have been used in an attempt to reduce the damage that has been caused by hydrogen sulphide and other corrosive substances produced with the crude in the Permian Basin Area.

One predominate success, in the writer's experience, is that obtained from aluminum decks for bolted tanks. There are tanks, in West Texas and New Mexico, on which aluminum decks have been in service in extremely corrosive areas for over twelve years, and these decks, when recently inspected, appeared to be in perfect condition. Unprotected steel decks installed in these areas normally last from eighteen to twenty-four months. The use of this material for such purposes was retarded for some time due to the cost, but now, with favorable price comparison many companies are making installations of aluminum decks on their bolted steel tanks, and some have even standardized on this type of material for decks.

The design of storage tanks has also evolved to a cone bottom type which has alleviated the problem of tank bottom accumulations. For many years, this design was considered impractical because of the foundation difficulties. A little over two years ago an operator in the Permian Basin Area installed a cone bottom tank and for a foundation

Continued on Page 26

The Group attending the May 16 Meeting.

Gulf Coast Section Activities

By J. E. Kastrop

May Meeting

Whether or not an exceptionally well-executed and informative program plus a large attendance at the May 21 meeting was due to the absence of both our chairman, Owen Thornton, and vice chairman, Ernie Miller, cannot be determined at this early date; however, the fact remains that 112 members and their guests found the subject, "The Hydrafrac Process" of such keen interest that William D. Owsley, the principal speaker, spent an hour during the discussion period giving additional data.

A. B. Stevens, vice chairman from A&M College of Texas, presided. Although Owsley's successful background from field engineer to technical adviser for Halliburton Oil Well Cementing Co. was brought up to date, he really needed no introduction to the Houston group. He became well acquainted in this area when he served as division engineer for Halliburton many years ago. He talked on this subject before the Mississippi Sub Section at their May 18 meeting in Brookhaven, which meeting was reported in the June issue.

The Hydrafrac Process, which was presented in full in the January JOURNAL in a paper by J. B. Clark, was developed originally by the Stanolind Oil and Gas Co. at their Tulsa laboratories. The industry received first formal reports of this revolutionary well-rejuvenation process at the October 1948 Petroleum Branch meeting in Dallas, where Clark presented the method as it had been developed up to that time along with results obtained.

Since that time, the Halliburton organization has been licensed to use the process and has shown remarkable successes through its application. As technical adviser, Owsley has been very closely associated with the process and the development of equipment used in fracturing the formations.

In addition to basic principles involved, the speaker presented many production case histories of the new process since it was last reported upon. Particular reservoir conditions under which the method is applicable and from which best results can be expected were given.

Considerable information was developed during the discussion session. Questions were asked about the details of the procedure followed in applying the process. Much time was spent on the problem of whether or not the formation split vertically or along bedding planes. Permeability profiles taken before and after fracturing the formations indicated that both vertical and horizontal splitting can be expected under some conditions. In this connection, a word of warning was issued, in that splitting into a gas cap or into a water zone must be avoided lest the process defeat its purpose. Considerable study of the well must necessarily precede any fracturing work. Shales, for example, tend to compress and will take up large volumes of fluid, preventing it from fracturing the oil producing formations.

A pressure of one pound per square inch per foot of depth is considered the overburden pressure; however, in actual practice, fracturing occurred in most cases with an average of only .75 pounds per foot of depth. In one case, which could not be explained, the pump pressure exceeded the one pound per foot figure, and the pumps were stalled without results.

July Field Trip

An interesting field trip is scheduled for the July meeting. The Gulf Coast Section members and guests will be taken on a tour of the Houston Ship Channel and a trip down the San Jacinto River to the San Jacinto Battle Grounds. This outing will terminate the Section's activities for the summer. There will be no meeting for the month of August; the next meeting will follow in September. ★ ★ ★

PERMIAN BASIN SECTION

Continued from Page 25

set it on an earthen mound of soil being shaped to accommodate the form of the bottom.

The idea spread and at the present time many operators have included the cone bottom tank into their standard installations.

Seam and joint leakage in the bolted steel tanks also has been a problem for many years. The normal rubber gasket materials usually deteriorate within three to four years requiring the rebuilding of the tank to install the new gaskets. Synthetic gasket materials have reduced materially the necessity for replacement, and the manufacturer also has developed methods of lapping joint gaskets that provide satisfactory seal at the points where it was formerly necessary to apply wicking material.

It is, of course, very desirable that lease operating personnel give constant attention to strict maintenance programs. This program should attract the problem from all angles including the exterior of tanks, conservation, interior maintenance, and from the standpoint of safety.

Regardless of the type of material or the fabrication methods that may be used in the construction of tankage, we must properly install and maintain the units to expect maximum results from them. Only by coordinated selection and maintenance programs within each organization and within the industry, is it possible for all the various factors to be properly evaluated to obtain the most beneficial effects.

Operators, manufacturers, and associated services must continue to pool all information gained by experience to insure that new and effective features and/or materials are developed and placed in use.

Wherever problems are encountered, a cooperative program should be initiated to gather available data towards the solution of the problems.

Personals

ALDEN S. DONNELLY, of Midland, was elected a vice president and a member of the board of directors of Honolulu Oil Corporation at the recent annual meeting of the stockholders of the organization held in San Francisco. ★★

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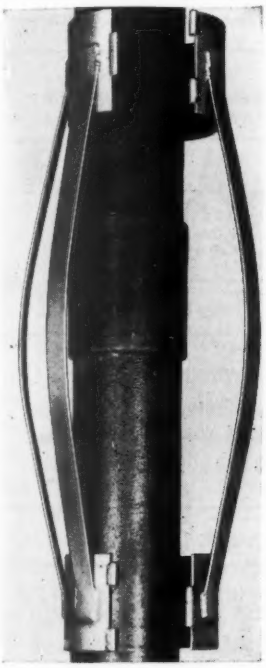

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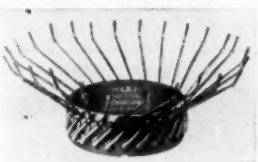

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ALL INSTITUTE SECTION

APPEARING IN:
- MINING ENGINEERING
- JOURNAL OF METALS
- JOURNAL OF PETROLEUM TECHNOLOGY

Text of Bylaw Amendment to Increase Dues Decided by Board at May 18 Meeting

Numerous matters of more than routine interest engaged the attention of the fourteen Directors who attended the Board meeting at Institute headquarters on May 18. Beginning with an informal luncheon session at 12:30 the meeting continued until 5:40. President Young presided, with the following Directors present: Messrs. Alford, Daveler, Elkins, Fletcher, Head, Kinzel, Kraft, Meyerhoff, Peirce, Phillips, Price, Schumacher, and Sullivan. Sixteen staff members and guests also attended.

The text of proposed amendments to the bylaws was discussed at some length with Edward Holloway, counsel, and the wording as given on another page of this issue was approved. The changes will be voted upon by the Board, according to the bylaws, at a meeting at least two months subsequent to May 18. They will provide for: (1) An increase of $5 in the dues of Members and Associate Members for the years 1950, 1951, and 1952; and for an increase in the dues of Junior Members of $2 for the same years; dues thereafter are subject to a referendum in 1952. (2) A change in the date when dues become payable from Oct. 1 to Jan. 1; members will receive the January, February, and March issues of the journals pending receipt of dues. (3) Elimination of the grade of Junior Foreign Affiliate at the end of 1949. (4) Limiting the term of Student Associateship to the end of the year of graduation, instead of the end of the following year as is the current provision. A special effort will be made to have graduating Student Associates apply immediately for a change of status to Junior Member, though action on their applications will not take effect until the end of the year.

Another matter that aroused considerable interest was the content of the All-Institute Section (Section 2) of the monthly journals. A difference of opinion developed as to whether all personals should be carried in this section, or whether they should be split up into items of particular interest to the three Branches and be published separately in Section 1 of the respective journals. Further discussion of this subject was postponed until the June meeting of the Board.

The advertising situation in the three journals was also reviewed. The mining journal is running somewhat ahead of M&M for the same months of 1948; the metals journal has contracts for $14,000 of the $15,000 income budgeted for the year; and the petroleum journal hopes for $20,000 this year, and at least double that two years hence.

With deep appreciation, especially so at this time, the Board received news of a bequest of £1000, free of English duty, which was left to the AIME in the will of one of its Life Members, William Henry Corbould, who died on March 16.

Reports were made of a preliminary study on the possibility of reducing expenses at AIME headquarters by a merging of certain activities of the four Founder Societies. It is believed that business machines might then be utilized which are not now practical for one society to use. The possibilities are to be investigated further.

A final financial report of the Annual Meeting in San Francisco was made, indicating that registration fees had netted $3708; tickets for various functions, $31,263; and contributions, $13,341. Of the last-named figure, 196 members donated $2381 and 75 manufacturers and companies gave $10,960. Total income was therefore $48,313. Expenses paid for by the San Francisco Section, including $947 returned to New York headquarters to pay a part of the cost of staff assistance at the meeting, amounted to $41,192, leaving a profit to the Section of $7120. This will be invested and used to help in defraying the expenses of future meetings, and to support Section activities. The AIME will have certain expenses not covered in the foregoing figures—chiefly traveling expenses of staff members from New York and Dallas.

Two tellers were appointed from each Branch to count the votes in the referendum for the increase in dues, as follows: Mining, F. X. Corbett and Robert B. Sterns; Metals, David Swan and Thomas A. Read; Petroleum, K. E. Hill and J. I. Laudermilk. The ballots will be counted on June 13, and a report made to the Board at its meeting on June 15. (Results of the balloting show that of the 11,618 ballots mailed, 6,923 valid ballots were returned, 5,403 voting yes, 1,520 voting no. For a tabulation of results see box on page 236.)

Certain changes were voted in the territory of Local Sections in eastern Pennsylvania. The Pennsylvania Anthracite Section's area will be confined to the counties and parts of counties in which there are anthracite mines; the Lehigh Valley Section will hereafter include Cornwall, Lebanon, Lehighton, and Palmerton; and the Philadelphia Section will include some of the area north of Philadelphia heretofore in Lehigh Valley Section territory.

Announcement was made of a survey being made for the U. S. Government to determine which members of various engineering societies have had experience in research and development, and have served in foreign countries. Members of the AIME will shortly receive a questionnaire for this purpose, and its prompt return, filled out as requested, will be appreciated. The work is being done on a contract basis by the ASME, with the co-operation of Engineers' Joint Council.

Ray P. Walters, AIME delegate to the recent World Engineering Congress in Cairo, submitted a detailed report of the meeting to the Board. He felt that technically the Congress was largely a failure. Strong efforts were made by Soviet countries to make political capital out of the meeting, but without much success.

A new Student Chapter, AIME, was recognized at the Institute of Technology, St. Louis University, with Albert J. Frank as Faculty Sponsor. Endorsement was again voted for the Welding Research Council, and its application for $1000 from the Engineering Foundation for its work in 1949. Fred M. Nelson was appointed to the Lucas Medal Committee for a four-year term, and Curtis L. Wilson was reappointed as AIME representative on Engineers' Council for Professional Development for three years. The ECPD annual report was announced as now available. Announcement was made of the United Nations Scientific Conference on the Conservation and Utilization of Resources, to be held at Lake Success, N. Y., Aug. 17 to Sept. 6. The Committee on International Relations of Engineers' Joint Council (of which the AIME is a member) will co-operate.

Immediately before adjournment, a memorial resolution for Sydney Hobart Ball, who died on April 8, was read. It was prepared by Donald M. Liddell.

Proposed Amendments to AIME Bylaws

By direction of the Board of Directors at its meeting on May 18, 1949, the following proposed amendments to the Bylaws of the Institute are published, to be voted on at the July 27, 1949, meeting of the Board, to be held in New York City.

(Add words italicized; delete words in parentheses).

To effect a temporary increase in dues:

Article II, Section 2:

Change second sentence to read as follows: "Dues of Junior Members *shall be* $10 per annum for the first six years of membership as a Junior Member, and thereafter $15; *except that the foregoing dues of Members and Associate Members shall be increased by $5, and of Junior Members by $2, for each of the years 1950, 1951, and 1952 only, unless, as the result of a referendum in 1952, the dues shall be otherwise determined.*"

To effect a change in the date when dues become payable:

Article II, Section 2:

Change fourth and fifth sentences to read as follows: "All dues (for the succeeding calendar year) shall be payable in advance on the first day of (October) *each calendar year*, except as provided in this section, and notice to this effect shall be published in the (September) *December* issues of the monthly journals of the Institute each year. A bill shall be mailed to each member liable for dues (on or before) *prior to* the first day of (October) *January* in each year, stating the amount of the annual dues, date when payable, and the penalty and conditions incident to default in payment."

Article III, Section 2:

In the first sentence, change the word "four" to "three."

To eliminate the class of Junior Foreign Affiliate at the end of 1949:

Article I, Section 1:

Revise first sentence as follows:

"The membership of the Institute shall comprise (seven) *six* classes, namely: 1. Members; 2. Honorary Members; 3. Senior Members; 4. Associate Members; 5. Junior Members; *and* 6. Rocky Mountain Members. (7. Junior Foreign Affiliates.)"

Article I, Section 8:

Delete entire section and renumber succeeding sections.

Article I, Section 10:

Revise first fifteen words as follows:

"Every candidate for election as a Member, Junior Member, *or* Associate Member (or Junior Foreign Affiliate) . . ."

Article I, Section 11:

Revise first sixteen words of second sentence as follows:

"Every person so elected shall become a Member, Junior Member, *or* Associate Member (or Junior Foreign Affiliate) . . ."

Article I, Section 12:

Revise first fourteen words as follows:

"If any person elected a Member, Junior Member, *or* Associate Member (or Junior Foreign Affiliate) . . ."

Article II, Section 1:

Revise first fifteen words as follows:

"Each newly elected Member or Associate Member, and each Junior Member (or Junior Foreign Affiliate) . . ."

Revise last sentence as follows:

"There shall be no initiation fee for Honorary Members *or* Junior Members (or Junior Foreign Affiliates)."

Article III, Section 1:

Revise first thirteen words of second sentence as follows:

"The resignation of a Member, Junior Member, *or* Associate Member (or Junior Foreign Affiliate) . . ."

Article III, Section 2:

In the first sentence, insert the word "or" before "Associate" and delete "or Junior Foreign Affiliate."

To restrict the time during which Student Associates may continue in that status:

Article I, Section 9:

Change the last sentence as follows:

"A Student Associate may remain such until December 31 of the year (following the year) in which he ceases to be in university residence as a student."

Nominees for Institute Officers in 1950

Pursuant to the provisions of the Bylaws as amended, herewith are printed short biographical sketches of the nominees on the official ticket for President, Vice-Presidents, and Directors for the Institute year 1950.

Chairman of the nominating committee of eighteen members is H. Y. Walker.

As provided in the amended Bylaws, 25 Members or Associates may transmit to the Secretary's office "any complete or partial ticket of nominees." If received prior to Sept. 1, a letter ballot will go to all members, containing both the official ticket and any supplementary nominations. If no supplementary nominations are received, according to the amended Bylaws, no letter ballot will be printed and the nominees on the official ticket "shall be declared duly elected at the meeting of the Board of Directors in November."

FOR PRESIDENT AND DIRECTOR

Donald H. McLaughlin, president of the Homestake Mining Co., has served his profession, and the Institute, long and well. A lot of study, traveling, and hard work have filled his 57 years. He graduated from the University of California in 1914, and took his doctorate from Harvard three years later. After two years in the Army, he came back to begin a stellar career. In 1920 he joined Cerro de Pasco and soon after, as chief geologist was directing the world's second largest geological department.

From 1925 to 1941 he was a professor of mining engineering and mining geology at Harvard, until called to the University of California at Berkeley to serve as dean. During these years, he maintained a consulting practice, serving Homestake and mining organizations throughout the world. Dean McLaughlin became vice-president and director of Cerro de Pasco in 1943. Two years later, he took over the leadership of Homestake. At AIME, Dr. McLaughlin headed the first Committee on Geophysics, and has served on the Mining Geology and Papers and Publications Committees.

FOR VICE-PRESIDENT AND DIRECTOR

Andrew Fletcher is president and treasurer of the St. Joseph Lead Co., and vice-president and treasurer of the AIME. He's a New Yorker, and was 54 last Feb. 6. Mr. Fletcher first worked as a shipyard mechanic in Wilmington, Del., after graduation from Yale's Sheffield Scientific School. Within a short eight years he headed the Fletcher Shipyard in Hoboken, N. J. Maintaining an interest in St. Joe, he became a trustee in 1921, and has been on its executive committee since 1922. Mr. Fletcher is also chairman of the board of the Industrial Hygiene Foundation of America.

Robert W. Thomas, a director of the Institute from 1944 to 1947, and a vice-president since the latter date, has been an engineer for 37 years. He is 63, and general manager for the Nevada Consolidated Copper Co.

Born in St. James, Minn., he graduated from the University of Kansas in 1911. Beginning with the Ray Consolidated Copper Co. as a junior engineer, he moved steadily upward, became superintendent of mines in 1924, and latterly has been general manager at Ray.

FOR DIRECTOR

Harold Decker, 45-year-old petroleum engineer, is assistant manager of the Pan American Production, Pipe Line, and Gas Co. in Houston, Texas. Born in Chicago, he graduated from the University of Oklahoma in 1925. Since then he's been associated with a total of six oil firms, including the Skelly Oil Co. in Tulsa and the Seaboard Oil Co. of Delaware, where he was production superintendent for four years.

Francis B. Foley, superintendent of research for the Midvale Co., Philadelphia, began his metallurgical career with the Company back in 1905, serving there for twelve years. A year of teaching at the University of Minnesota was followed by various activities, including research work with the Bureau of Mines, and collaboration with the late, famed Dr. Henry Marion Howe. In 1926 he rejoined Midvale, assuming his present job. Mr. Foley, a graduate of Girard College, is 61.

Edward C. Meagher, a mining engineer, and president of United Engineering Trustees, Inc., was born in Hoboken, N. J., on Oct. 2, 1897. He attended Columbia University, taking a B.S. degree in 1917, and four years later, an E.M. from the School of Engineering. Mr. Meagher's entire professional career has been spent with the Texas Gulf Sulphur Co. He began there in the sales department in 1921, and is now the firm's treasurer.

Charles Van Ormer Millikan, chief petroleum engineer for the Amerada Petroleum Corp., Tulsa, Okla., has been active in the Petroleum Division since its formation, and was its Chairman in 1930.

Mr. Millikan, 53, is a native Oklahoman and a graduate of Oklahoma A&M. He served in the Navy during World War I, returning to take his M.S. degree from the University of Pittsburgh in 1920. After gathering experience in the Appalachian oil fields for two years, he returned to Oklahoma to join Amerada. He was awarded the Institute's Anthony F. Lucas Gold Medal in 1944.

Howard I. Young, 60, president and general manager of the American Zinc, Lead and Smelting Co. in St. Louis, has spent most of his career in the mining industry. He attended Springfield Business College, joined the firm he now heads in 1908, assuming charge of Missouri mining operations six years later, and becoming president and general manager in 1930. He has been president of the American Mining Congress and the American Zinc Institute.

Gail F. Moulton is a geologist for the Chase National Bank in New York, and a Vice-Chairman of the Petroleum Division, AIME. He is 51, and a graduate of the University of Chicago. Mr. Moulton has 31 years of experience in the petroleum world, formerly headed the petroleum section of the Illinois State Geological Survey, and is a prolific writer in his field.

Division Nominations for 1950

Following are the names of those nominated by the Nominating Committees of the various Divisions for officers for the coming year. In general, the bylaws of each Division provide for additional nominations by petition:

Coal Division: Chairman, Carroll F. Hardy; Chairman-elect, Carroll A. Garner; Executive Committee (until 1953), A. Lee Barrett, Claude P. Heiner, Richard H. Swallow.

Extractive Metallurgy: Chairman, Carleton C. Long; Chairman-elect, Oliver C. Ralston; Secretary, T. D. Jones; Executive Committee (until 1953), Russel B. Caples, A. C. Loonam.

Industrial Minerals: Chairman, Richard M. Foose; Secretary-Treasurer, G. Richards Gwinn; Eastern Vice-chairman, John H. Melvin; Southeastern Vice-chairman, Arthur J. Blair; Rocky Mountain Vice-chairman, Jack C. Pierce; Western Vice-chairman, George D. Dub; Canadian Vice-chairman, Elwood S. Moore; Executive Committee (until 1953), Ian Campbell, Joseph L. Gillson, Stanton Walker.

Institute of Metals: Chairman, Maxwell Gensamer; Senior Vice-chairman, Robert M. Brick; Vice-chairman, Henry L. Burghoff; Secretary, E. O. Kirkendall; Executive Committee (until 1953), William M. Baldwin, Jr., Paul Adam Beck, Alexander Squire.

Iron and Steel: Chairman, H. K. Work; Vice-chairmen, Roy A. Lindgren, Alvin H. Sommer, William A. Steele; Executive Committee (until 1953), Karl L. Fetters, D. L. McBride, George B. McMeans.

Mineral Economics: Chairman, Charles H. Behre, Jr.; Vice-chairmen, Clayton G. Ball, Richard J. Lund, Charles White Merrill; Secretary-Treasurer, Joseph A. Corgan; Executive Committee (until 1953), Simon D. Strauss, W. W. Mein, Jr., and R. J. Bradley.

Mineral Industry Education: Chairman, Allison Butts; Vice-chairman, Harry H. Power; Executive Committee (until 1953) James D. Forrester, John R. Spielman, J. W. Stewart.

Minerals Beneficiation: Chairman, Grover J. Holt; Associate Chairman, Raymond E. Byler; Regional Vice-chairmen, Edwin H. Crabtree, Jr., Donald W. Scott; Secretary-Treasurer, Will Mitchell, Jr.; Committee Chairmen—Membership, James A. Barr, Jr.; Papers and Publications, M. D. Hassialis; Program, Raymond E. Byler; Education, S. R. B. Cooke; Concentration, Milton LeBaron; Materials Handling, Stanley D. Michaelson; Crushing and Grinding, Fred C. Bond; Solids-Fluids Separation, F. W. McQuiston, Jr.; Operating Control, F. M. Lewis; Solution & Precipitation, Max W. Bowen; Pyrolysis & Agglomeration, Fred D. DeVaney; Richards Award, E. H. Rose, J. F. Myers; Symposium, A. F. Taggart; Nominating, T. B. Counselman.

Petroleum Division: Chairman, John E. Sherborne; Vice-chairman, Paul Andrews; Executive Committee (until 1953), R. W. French, R. C. Earlougher, John R. McMillan.

Results of the Balloting on Increased Dues

Ballots mailed 11,618

Branch	Yes	No	Percent Yes
Mining	2,258	651	77.5
Metals	1,339	366	78.5
Petroleum	1,306	357	78.5
Other	500	146	77.4
Total	5,403	1,520	78.2

What Went on at Recent Local Section Meetings

SECTION	DATE	ATTENDANCE	SPEAKER, AFFILIATION, AND SUBJECT
Arizona, Morenci Subsection	April 12	33	William Distler, "Proverbs for the Young Engineer." J. E. Skipper on the Morenci power plant and the future of the gas turbine.
Black Hills	May 6	90	Joint meeting, Woman's Auxiliary and Student Associates from S. Dak. School of Mines & Technology. J. V. N. Dorr, The Dorr Co., on early development of Dorr equipment in Black Hills.
Boston	May 2	72	Joint meeting with Woman's Auxiliary. Seville R. Davis, American editor, Christian Science Monitor. "Analysis of Postwar U. S. Foreign Policy in Europe."
Carlsbad Potash	May 12	52	J. Harlan Johnson, Colorado School of Mines, comments on International Geological Congress.
Columbia	May 14	120	Third Annual Northwest Industrial Minerals Conference.
Cleveland	May 12	.....	Harry A. Schwartz, National Malleable & Steel Castings Co. "Correlation of Physical Properties with Chemical Composition in Low Alloy Cast Steels."
Detroit	May 16	.....	A. C. Cooley, General Electric Research Lab. on metallic sheet.
Mid-Continent	April 9	100	John T. Hayward, Barnsdall Oil Co., on unique design for offshore drilling structures.
Montana	April 26	130	R. H. Townsend, Anaconda Copper Mining Co., on ferromanganese operations.
Montana	May 27	.....	Joint meeting with Last Chance Gulch Mining Assn. W. R. Wade, Rainbow Mining Co., on the Marysville district.
New York	May 18	75	J. D. Doherty, office of synthetic liquid fuels, Bureau of Mines, "Synthetic Oil—Security for the Future."
Ohio Valley	May 18	22	Film, "Ohio and its Mineral Resources." Progress report on AIME Mid-Year Meeting.
Pennsylvania-Anthracite	April 22	195	S. H. Ash, chief, safety branch, Bureau of Mines, on anthracite flood-prevention project.
St. Louis	April 22	86	J. G. Evans, Gardner-Denver Co., on mining experiences in South Africa.
Utah	April 21	44	Clayton Wolf, Univ. of Utah engineering experiment station, on use of noncoking coal in metallurgical processes.

Engineering Index Volumes Wanted

Copies of the bound volumes of Engineering Index from 1928 to date are needed by various libraries and organizations, both in this country and abroad. If you have volumes that you do not need, please get in touch with Ralph H. Phelps, director, Engineering Societies Library, 29 West 39th St., New York City 18.

The Drift of Things

The Referendum

One may look at the results of the referendum on increased dues in one of two ways. It may be considered reassuring that three fifths of the AIME members qualified to vote returned their ballots, and that four out of five of them voted for the increase although it definitely meant an out-of-pocket expense to them for the next three years. Also, it is good to know that all three Branches—Mining, Metals, and Petroleum—show the same four-to-one ratio in favor of increased dues.

But speaking as Secretary of the AIME, we choose to look at the vote with something less than complete satisfaction. Serious thought should, we believe, be given to the fact that some 1500 members do not seem to think the service they are getting, or are likely to get in the future, is worth more than the $15 or the $10 that they have been paying for the the last three decades, in spite of the acknowledged greatly increased cost of practically everything. Also, in spite of what we are assured was an excellent percentage of returns, the fact remains that about two fifths of the Institute membership was too busy or not sufficiently interested to vote at all. Although they were not actively against the proposed increase in dues, they did not support it, even to the extent of making a couple of check marks, signing their name, and dropping a postal card into the nearest letter box.

Unquestionably, much more work must be done in making the Institute what its members want it to be. Most tangible of the services that can be improved, of course, are the publications—monthly journals and books, and the meetings—annual, mid-year, Divisional, and Local Section. But also the officers, Directors, and headquarters staff of the AIME must get closer to the members, must think about and talk over each others' problems, and must discover what new fields offer promise of better service to members.

We feel that a good start has been made, but far more must be accomplished in the next three years. At that time another referendum will be taken, and it is hoped that in the meantime it will be possible to increase advertising income, the sale of books, and the number of members sufficiently to make a return to the current dues schedule possible. Other avenues of income may also be developed, or methods of cost cutting devised, so that the standard of services to AIME members can be maintained, or even expanded, even though prices will not have retracted to the prewar level.

Those of us whose responsibility it is to run the Institute must, in the next three years, justify our stewardship. But the AIME is a co-operative enterprise, and the best results can only be secured if the members at large also will aid in every way they can to secure and prepare more and better papers, and to hold more interesting meetings.

Reviewing the First Six Months of the New Journals

At the Board meeting last September, approval was given for the three new journals whose publication began with the issues for January 1949. According to the minutes of that meeting, "Section one of each of the journals would be devoted to advertising and editorial matter of specific interest to the individual Branch and to be secured, edited, and wholly under the control of the Branch council or editor. Section two would be common to all three journals and would consist of feature articles, shorter material, and professional news prepared and edited at Institute headquarters but of a wide interest and character to be approved by each Branch council or editor. Section three would consist of technical papers of interest to the respective Branches, as now published in the Technologys." It was planned at that time that Section one of the three journals would average about as follows, as to number of pages per issue: Mining, 48; Metals, 16; Petroleum, 32. Section two would average about 24 pages for each of the journals. The actual number of pages for the first half year has not been greatly different from these estimates. Section three averages were: mining, 37; metals, 65; and petroleum, 28 pages.

At the May Board meeting, proposals of the three editors were advanced to reduce the size of Section two (the All-Institute section) to an average of about eight pages per month. This would involve elimination of all personals and obituaries from the All-Institute section and assigning them to Section one, according to Branches. The material still to be put in Section two would include reports of Board meetings, a page or two of the Drift of Things, the calendar of coming meetings, a summary table of Local Section meetings, a list of the titles of all technical papers published in the three journals with a definitive sentence as to the subject covered, a list of those applying for membership (though this might be split according to Branches and published in Section one), publicity regarding Annual and Mid-Year meetings, short book reviews of general interest, brief Woman's Auxiliary news, and short biographies of the President and new Directors each year. An occasional feature article might be used if space permitted. The annual reviews, which bulked so large in the March issue, would be split up and published only in the journal covering their specific field.

Those present at the Board meeting were, of course, the more mature members of the Institute, and they expressed considerable opposition to further condensation of the All-Institute section, particularly as to elimination of the personals. Their interests are naturally broad, and their friends and acquaintances fall into all three Branches. They pointed out that the present scheme of publishing has met with almost unanimous approval and they urged that no further change be made until at least one full year has been completed. In the meantime, however, the editors will welcome comment from members as to the type of material they like in the present journals, and what classes, if any, they do not find of interest.—*E. H. R.*

Mid-Year Meeting News

Governor Lausche

A Message from the Governor of Ohio

"I am happy to learn that the 1949 Mid-Year meeting of your Institute is going to be held in Columbus, Ohio, the week of September 25th.

"It is a pleasure and privilege to welcome the officers, members, and guests of your organization to our Capital City.

"It might interest you to know that Ohio is one of the leading mineral producing states, with coal, oil and gas, limestone, clay, glass sand, salt, gypsum, and numerous other minerals all mined within our borders. Ohio is also rich in scenic attractions and historical lore.

"I am, therefore, pleased that you have chosen our state as the place for your meeting, and I know that in the friendly atmosphere of Columbus your sessions will be both enjoyable and educational."

FRANK J. LAUSCHE,
Governor, State of Ohio

A Message to Members:—

The Mid-Year Meeting of the Institute, scheduled for Columbus during the week of September 25, 1949, will afford a splendid opportunity for members and their friends to participate in an outstanding technical program. There will be papers and conferences on current problems of industry, management, and technical education in the mineral technology field; and inspection trips to some of the nation's finest industrial and research plants.

A most cordial welcome has been extended to all Institute members to visit Columbus on this occasion by the Governor of Ohio, the Mayor of Columbus, and the officers of the great industrial, research, and educational institutions, as well as by the Ohio Valley Section of the Institute.

The AIME Directors hold their September meeting at Columbus on September 27, with representatives of the Sections and Divisions present to discuss the program and progress of the Institute. The social functions planned for the ladies, as well as the members, will add greatly to the pleasure of the meeting. Adequate hotel accommodations are assured.

On Friday, Sept. 30, the Southern Ohio Section of the Open-hearth Committee, AIME, will begin a two-day meeting, also at Columbus, so many members will find that their time can be profitably occupied for the entire week.

The Mid-Year Meeting presents a splendid opportunity for many who could not be at San Francisco to participate in an important national gathering of mining and petroleum engineers and metallurgists for which most diversified programs have been arranged.

L. E. YOUNG,
President, AIME

Women Plan Gala Meeting

Several hundred women from all parts of the country will arrive in Columbus on September 24 with their engineer spouses, and the Columbus Section of the Woman's Auxiliary, AIME, will play the gracious hostess during the Mid-Year Meeting. Mrs. Elmer R. Kaiser, 2406 Brixton Rd., Columbus, general chairman of the ladies' committee, has been busy arranging the entertainment.

Following the All-Institute luncheon on Monday afternoon, the ladies have scheduled a sightseeing trip through Ohio's capital city, winding up the day with a tea at the home of the president of Ohio State University. Tuesday will feature a visit to the Heisey Glass Co. at Newark, Ohio, lunch at the Granville Inn, and then a tour of the plant where the new Lustron houses are made. A fashion show and luncheon at the Maramor, famed Columbus restaurant, will be Wednesday's high spot, but the ladies will go higher that evening to dine with their husbands atop a forty-story skyscraper in the heart of the city. A romantic nocturnal visit to the local observatory is planned for later that night, with a planetary display on the agenda.

Columbus's Mayor Welcomes the AIME

"Columbus appreciates the honor and privilege of playing host to the American Institute of Mining and Metallurgical Engineers.

"Columbus is the heart of a great state. It is Ohio's capital city. Meeting in Columbus is traditional, for hundreds of conventions are held in our city each year. There are many fine hotels and restaurants to accommodate visitors.

"It's easy to come to Columbus. Our city is conveniently accessible to the country's principal metropolitan centers by air, rail or highway. One half of the nation's population resides within a 500 mile radius of Columbus.

"We urge you to attend your mid-year meeting. We know you'll enjoy your stay, although brief, in Columbus."

JAMES A. RHODES, Mayor,
City of Columbus, Ohio

Mayor Rhodes

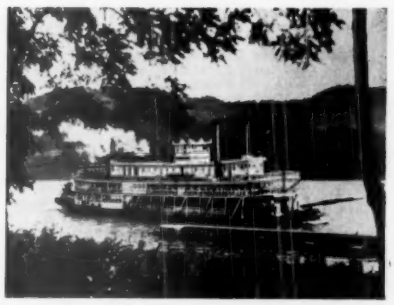
Part of the broad and beautiful campus of Ohio State University in Columbus, where 2600 educators serve a student body numbering 24,000. This is but one of the 54 colleges and universities which make Ohio one of the nation's best educated sections.

Ohio the Great

Ohio, native state of eight Presidents, seventh in rank among the states producing industrial minerals, leading the world in rubber, steel, and clay products, will play host to the AIME in September. Ohio is the Iroquois word for "great." Ohio's great, and our Mid-Year Meeting will be the same.

There'll be plenty of vacationing to do in the Buckeye State when technical sessions are over. Five hundred and thirty miles of rivers and a 230-mile frontage on Lake Erie furnish scenic beauty, and direct commerce routes with the world. Great steel and other industries along the waterways move observers to label Ohio "The Ruhr of America." A storehouse of minerals lies below the fertile farmland, and 117,000 businesses operate atop it. Columbus, the state capital, with the Scioto River winding like a ribbon through her hair, awaits Mr. and Mrs. AIME.

Ohio is mostly farmland, but oil derricks hold up the sky, and the world's largest sandstone quarry (right) is in S. Amherst. The soil over which the pioneers traveled in 1788 now yields a rich harvest of food, and the minerals vital to commerce.



In the Buckeye State, heavy industry joins with ante-bellum charm, providing lifeblood for the world's commerce, and pleasure for visitors. Up and down the Ohio and Muskingum rivers flow the iron ore, coal, and limestone which keep the blast furnaces going.

Among the Student Associates

Mackay Grads Feted by Reno Section

The twenty-two members of the graduating class at the University of Nevada's Mackay School of Mines were the honored guests, on May 5, at a luncheon meeting of the Reno Section, AIME. Chairman A. C. Johnson presided, and called upon Jay A. Carpenter to introduce the graduates individually.

All twenty-two graduates are Student Associates of the AIME, credit for this fine record going to H. B. Chessher, Sr., chairman of the Reno Section's membership committee. Alberto Barrios, retiring president of the Crucible Club, addressed the gathering, and then went on to provide fine entertainment, singing and accompanying himself on the guitar.

Lehigh University

The Howard Eckfeldt Society met for the last time this year on May 19, viewing a film and electing officers for next year. The film was a Phelps Dodge Copper Co. presentation, showing mining and milling operations at Bisbee, Ariz.

The men who'll pilot the Society through the next year are: President Robert L. Smith; Vice-President Robert A. Limons; Treasurer Joseph A. Holmes; and Robert E. Nolan, Jr., Secretary.—*Robert E. Nolan, Jr., Secretary.*

Calendar of Coming Meetings

JULY
7 Reno Branch, Nevada Section, AIME.
9-23 Fourth Empire Mining and Metallurgical Congress, Great Britain.
13 El Paso Metals Section, AIME.
13 Southwestern New Mexico Section, AIME.
13-15 American Society of Civil Engineers, summer convention, Mexico City.
15-24 Pan-American Engineering Congress, Rio de Janeiro.
19 Gulf Coast Section, AIME.
25 Alaska Section, AIME.

AUGUST
23-26 AIEE Pacific general meeting, Fairmont Hotel, San Francisco.
26-Sept. 10 Engineering & Mining Exhibition, London, England.
Aug. 17-Sept. 6 United Nations Scientific Conference on the Conservation and Utilization of Resources, Lake Success, N. Y.

SEPTEMBER
25-28 American Mining Congress, Metal Mining Convention, Hotel Davenport, Spokane, Wash.
25-28 Mid-year Meeting, AIME, Neil House, Columbus, Ohio.
29-30 ASME, fall meeting, Erie, Pa.
29-Oct. 1 Colorado School of Mines, 75th anniversary celebration.
Sept. 30-Oct. 1 Southern Ohio Section of Open Hearth Committee, AIME, fall meeting, Deshler-Wallick Hotel, Columbus.

OCTOBER
5-7 Petroleum Branch, AIME, fall meeting, Plaza Hotel, San Antonio, Texas.
13-14 Texas Mid-Continent Oil and Gas Association, annual meeting, Rice Hotel, Houston.
14 Eastern Section, Open Hearth Committee, Iron and Steel Division, annual all-day fall meeting, Warwick Hotel, Philadelphia.
14 Southwestern Section, Open Hearth Committee, Iron and Steel Division, Kansas City, Mo.
17-19 Institute of Metals Division, AIME, fall meeting, Allerton Hotel, Cleveland.
17-23 AIEE, 1949 Mid-West meeting, Netherland Plaza, Cincinnati.
20-21 Petroleum Branch, AIME, Elks Club, Los Angeles.
24-28 Thirty-seventh National Safety Congress and Exposition, Chicago.
26-27 Joint Fuels Conference, ASME-AIME, French Lick Springs Hotel, French Lick, Ind.
28 Pittsburgh Section of Open Hearth Committee and Pittsburgh Section, AIME, annual fall meeting, William Penn Hotel, Pittsburgh.
28-29 ECPD, annual meeting, Edgewater Beach Hotel, Chicago.

NOVEMBER
1-5 Pacific Chemical Exposition, California Section, American Chemical Society, San Francisco Civic Auditorium.
2-4 American Society of Civil Engineers, fall meeting, Washington, D. C.
7-10 AIChE, annual meeting, Pittsburgh, Pa.
9-11 Industrial Minerals Division, AIME, Tampa, Fla.
12-14 Geological Society of America, annual meeting, Hotel Cortez, El Paso.

DECEMBER
7 American Mining Congress, Annual Business Meeting, New York City.
8-10 Seventh Annual Conference, Electric Furnace Steel Committee, Iron and Steel Division, AIME, Hotel William Penn, Pittsburgh.

JANUARY 1950
18-20 American Society of Civil Engineers, annual meeting, New York.
30 AIEE, winter meeting, New York.

FEBRUARY 1950
10 Southwestern Section, Open Hearth Steel Committee, Iron and Steel Division, St. Louis, Mo.
12-16 Annual Meeting, AIME, Statler (Pennsylvania) Hotel, New York City.

APRIL 1950
2-4 Annual conference, National Open Hearth Committee, Iron and Steel Division, Cleveland, Ohio.
10-12 Open Hearth Conference, and Blast Furnace, Coke Oven and Raw Materials Conference, Netherland Plaza Hotel, Cincinnati.
19-21 American Society of Civil Engineers, spring meeting, Los Angeles.

DECEMBER 1950
7-9 Eighth Annual Conference, Electric Furnace Steel Committee, Iron and Steel Division, AIME, Hotel William Penn, Pittsburgh.

University of Nevada

At the April 27 meeting of the Mackay School of Mines' Crucible Club, Mr. Zadra, of the Rare Metals Station of the Bureau of Mines in Reno, presented, for the first time, his paper on the electrolytic deposition of gold from activated charcoal. The students found the session most interesting and educational.

The Club then went on to elect officers for next year. Fred Muller is the new President, with John Cunningham, Walter Johnson, and Harry Varischetti serving as Vice President, Secretary and Treasurer, respectively.

Club members can now look back on a highly successful semester of activities. W. E. Wrather, USGS head, and former AIME President, addressed the group in February, and the March gathering heard a report from President Barrios on the AIME Annual Meeting in San Francisco. Since the first of the year, the Club has sponsored several movies for students and the public, including films on the natural resources of Nevada, block caving methods at the Emma Nevada mine in Kimberly, and one on the various types of Marion shovel in operation. The alumni paper, "The Mackay Miner," was published during the first week of May, and mailed to alumni, former students, and friends of the club.—*Walter B. Johnson, Secretary.*

University of New Hampshire

An aerial field trip, aimed at studying the glacial features of Illinois, and made last summer by the students of the University of Illinois, was described to University of New Hampshire Student Chapter members at their regular April meeting. D. H. Chapman, associate professor of geology at New Hampshire, described the airborne venture, which he had directed, and illustrated his talk with excellent color slides.

New officers for the coming year were elected at another April meeting. New Chapter President Lawrence W. Wakefield is ably supported by Vice-President Carl A. Lein; Secretary-Treasurer Mrs. Isabelle A. Kerdack; and Corresponding Secretary Livingston Chase.—*Marston Chase, Corresponding Secretary.*

News of AIME Members

Marshall B. Ames was transferred early in January by the Corps of Engineers from the Alaska district to the Walla Walla, Wash., district.

E. W. K. Andrau expects to do considerable research and prospecting for uranium in the Rocky Mountain area. The E. W. K. Andrau Enterprises has opened an office in Lander, Wyo., where it is expected that Dr. Andrau will in the near future do considerable geological work in addition to some drilling this year.

Murray R. Arrowsmith can be found in Kimberly, Nev., where he is working as a geologist for the Consolidated Coppermines Corp.

L. J. Barraclough, who is reached at the Disergarh Post Office, Burdwan District, W. Bengal, India, has been elected president of the Mining, Geological and Metallurgical Institute of India.

Ralph C. Beerbower, former district manager of the Goodman Mfg. Co., has taken the post of assistant to the superintendent of the H. C. Frick Coke Co., West Leisenring, Pa.

Chas. H. Behre, Jr., returned late in April from Rangoon, where, as representative of Behre Dolbear & Co., mineral advisers to the Burma Union Government, he had been discussing general plans for mineral development. The trip involved a round-the-world flight. He left to resume field work in Mexico on May 15, and on June 7 received an honorary degree of Doctor of Science from Franklin and Marshall College, Lancaster, Pa.

Josef W. J. Bercher is assistant division manager of the Texas Eastern Transmission Corp., P. O. Box 32, Downingtown, Pa.

Bernard Beringer, former assistant general manager of Randfontein Estates G. M. Co., is now mine manager of Palmiet Chrome Mines Ltd., P. O. Matooster, Rustenburg, Transvaal, S. Africa.

Charles W. Campbell has changed from the engineering department to the production department of Mina Tiro General, Charcas, S.L.P., Mexico, and is now shift boss at the property.

K. P. Campbell, working for the American Smelting and Refining Co., has been transferred from Chihuahua, Mexico, to the Company's general engineering department at El Paso, Texas.

William J. Coulter, Jr., is working as a miner for the Bunker Hill and Sullivan Mining and Concentrating Co. His address is P. O. Box 353, Kellogg, Idaho.

Orville R. Dahlberg, since graduating from the University of Wisconsin, has been employed by the Oliver Iron Mining Co. as a mining engineer on a training program, intended to acquaint future operators and engineers of the company with the various operations that comprise the company as a whole. Periods of varying lengths are spent under the different departments, such as engineering, special exploration, budget control, shops, grading, sampling and safety.

Rene Engel

Rene Engel, geologist and chemical engineer, recently became associated with **Florent H. Bailly,** petroleum engineer and geologist, founder and president of Oil Properties Consultants (geology and engineering) and Petroleum Engineering Associates (laboratory studies), both of Pasadena, Calif. Under the names of Petroleum Industry Consultants, Cuba, and Petroleum Industry Consultants, Venezuela, this association is extending its services from branches located respectively in Havana and Caracas. Dr. Engel still retains his post as curator of mineralogy and petrology at the Los Angeles County Museum.

Paul B. Entrekin

Paul B. Entrekin, former vice-president and manager of Bethlehem Chile Iron Mines, became manager of the Bethlehem Steel Company's mining division in May. A Lehigh graduate, Mr. Entrekin started with Bethlehem in 1925 as an engineer in the mining department. He was transferred to the Cornwall mine in 1926 to service successively as plant engineer, mine superintendent, and assistant manager. In 1941 he went to El Tofo, Chile, as mine superintendent and assistant manager of Bethlehem Chile, a Bethlehem Steel subsidiary, becoming manager and vice-president in 1944.

Lloyd L. Connell writes that his connection with the Stoker Manufacturers Association terminated on April 1 and that he is now with the Diamond Chain Co., Indianapolis, Ind. Following completion of his current period of training, he expects to be assigned to a territory as sales representative.

John M. Davis can be reached at the Western Machinery Co., 231 Healey Bldg., Atlanta 3, Ga. He had worked for the Phosphate Mining Co. in Florida.

Joseph M. Downey, formerly metallurgist at the Leadville milling unit of the American Smelting and Refining Co., is now a miner at the Kokomo Victory mine of the Company.

John R. Drenan has been appointed superintendent of the fluorspar division of the United States Coal and Coke Co. at Mexico, Ky., effective May 1.

L. E. Young, guest of honor at St. Louis Section—Missouri School of Mines Student Chapter banquet on May 14, with St. Louis Chairman Herbert Franke and Mrs. Franke.

L. E. Young, President of the AIME, spoke before the Missouri School of Mines Student Chapter on May 14. He discussed briefly technical assistance to foreign countries and then spoke at length on potash mining, illustrating his talk with slides and maps. The Student Chapter reports that Dr. Young's wide experience, coupled with natural speaking ability, gave a comprehensive picture of this type of mining, and members of the Chapter feel that this was the most important meeting in the history of the Chapter.

Gilbert C. Davis acted as manager of the Stag Canon branch of the Phelps Dodge Corp. from 1929 to 1939 when he was transferred to the Morenci branch where he was in charge of operations until 1946. At that time he was transferred to Douglas, Ariz., as director of labor relations, and continued in that capacity until his retirement on March 1. To go back thirty odd years, Mr. Davis went from Denver to the Rock Springs district to open a new coal mine for the Colony Coal Co. at Dines, Wyo., and was in charge of operations until 1927 when he moved to Mt. Harris, Colo., and for the next two years was general manager of the Colorado & Utah Coal Co. as well as the Colony Coal Co.

G. Dessau, an Italian mining engineer, who, after having been taken to India as a prisoner of war, was later allowed to work there and was in charge of the geophysical section of the Geological Survey of India from the start of that section, has now returned to Italy. He has again taken up service with the Italian Colonial Administration and has been attached to the Geological Survey of Italy.

O. J. Egleston has retired as vice-president and consulting engineer for the U. S. Smelting Refining and Mining Co. after 46 years with the Company and its predecessor. **A. B. Marquand** has also retired as vice-president and manager of metal sales after 31 years with the concern.

Andrew Fletcher, president of the St. Joseph Lead Co., and vice-president and treasurer of the AIME, delivered the commencement address at the Missouri School of Mines and Metallurgy, Rolla, on May 31. At the same time the University of Missouri conferred upon him the degree of Doctor of Engineering.

Milton H. Fies has been appointed a consulting engineer to the Office of Synthetic Liquid Fuels, Bureau of Mines. He will continue as part time manager of coal operations for the Alabama Power Co. Under Dr. Fies's supervision, the Alabama Power Co. is collaborating with the Bureau of Mines in a second field-scale experiment in the underground gasification of coal at Gorgas, Ala. A seam of coal there recently was ignited under carefully controlled conditions to determine the feasibility of using the gases thus produced as a source of fuel for boilers and as a raw material for making synthetic oil and gasoline.

Glenn H. Fritz left his job with the Anaconda Copper Mining Co. last December and is now employed by the Joy Mfg. Co. as a sales trainee.

J. Porter Gardner, Jr., formerly field ventilation engineer for the Joy Mfg. Co. at their New Philadelphia, Ohio, plant, was transferred on Jan. 1 to Joy's Chicago district sales office as sales representative specializing in fan sales.

Dion L. Gardner has moved his consulting office in geology and engineering to 1815 W. Chapman, Orange, Calif., c/o Association Laboratories. His office was in Santa Ana.

Fred E. Gray is living at the Asbury Apartment Hotel, 2505 W. 6th St., Los Angeles 5. He is assistant general manager of the Coronado Copper and Zinc Co.

I. G. Grossman, formerly at the department of geology at the University of North Dakota, is now with the petroleum economics branch of the Bureau of Mines in Washington, D. C.

Julius B. Haffner has been elected second vice-president of the Bunker Hill and Sullivan Mining and Concentrating Co. and **Donald H. McLaughlin** becomes a director of the Company.

Alfred S. Harvey, since graduation from the Missouri School of Mines and Metallurgy last June, has been quarry foreman for the U. S. Gypsum Co. at the Fort Dodge plant. He can be reached at 1111 S. 18th St., Fort Dodge, Iowa.

John S. Hemphill is now associated with C. A. Venezolana de Cementos, Caracas, Venezuela.

James M. Hill, formerly geologist with the Union Carbide and Carbon Co., has opened his office as a consulting mining geologist at 182 N. Court St., Tucson, Ariz.

Arne Hofseth is one of two Norwegian technicians who will spend six months in the United States studying mining methods and equipment which might be adapted for use in mine operations in Norway. They are particularly interested in modern methods of open pit mining, equipment used for milling and transporting ore, and American methods of pelletizing iron ore. The Bureau of Mines is co-operating with ECA's technical assistance division in arranging the studies.

John A. Johnson is supervisory engineer of the Duluth office of the Health and Safety Division of the Bureau of Mines.

Werner O. Joseph, upon graduation from the University of Chile, became assistant mill foreman of Cia. Minera Punitaqui in Ovalle, Chile.

Francis R. Joubin, for twelve years on the exploration and mine staff of Pioneer Gold Mines of British Columbia, and more recently engaged as their Eastern Canada representative, has been granted a leave of absence allowing him to assume charge of exploration projects for other companies. He will be retained as Pioneer's eastern adviser on exploration, and will continue to make his headquarters at the Pioneer company's offices at 510 Concourse Bldg., 100 Adelaide St., W., Toronto, Ont.

Nicholas N. Kohanowski, formerly with Cie. Aramayo de Mines en Bolivie, has returned to the States and accepted the post of assistant professor in the department of geology at the University of North Dakota, Grand Forks.

Emerson C. Lane, has gone to San Juancito, Honduras, as metallurgist for the New York and Honduras Rosario Mining Co.

H. F. Lynn informs us that he is now associated with the Southwestern Engineering Co., 4800 Santa Fe Ave., Los Angeles 11, Calif. He had been with the Western-Knapp Engineering Co.

Mark C. Malamphy, consulting geophysicist, formerly of Little Rock, Ark., and W. G. Garlick, consulting geologist of Lusaka, Northern Rhodesia, have incorporated under the firm name of Mark C. Malamphy & Co., Ltd., consulting geologists and geophysicists with offices in Mufulira, N. Rhodesia. Mr. Malamphy has been engaged in geophysical work in the United States, Canada, and South America since 1926, and in the Union of South Africa, the Rhodesias, and the Belgian Congo since 1946. Mr. Garlick has been doing geological work in South and Central Africa for about twenry years. The new firm's address is P. O. Box 209, Mufulira, N. Rhodesia.

Charles A. Marr is working for the St. Joseph Lead Co. at Bonne Terre, Mo., as a mining engineer.

Robert R. Mates, since school days at the University of Utah, has been employed by the Kennecott Copper Corp., Arthur, Utah, as a research engineer and by the Bureau of Mines at Salt Lake City as a metallurgist.

J. L. McCluggage is a mining engineer with the Kamunting Tin Dredging Co., Taiping, Perak, Malaya. He had held the same post with the Rawang Tin Fields, Ltd.

C. E. McManus has been appointed assistant to the general manager of the Minnesota mines of The M. A. Hanna Co.

Wilson D. Michell, after spending two years in French Morocco as geologist for the Societe Nord-Africaine du Plomb, engaged in the exploration and development of lead-zinc deposits in the northeastern part of that country, is now working as a geologist for the Resurrection Mining Co. at Leadville, Colo.

Arnold H. Miller, consulting engineer of New York City, has been in Sinaloa, Mexico, on professional work.

F. Stuart Miller has 50 S. Remington Rd., Columbus, Ohio, as a permanent address, but right now he is in Kuala Lumpur, Malaya, as assistant manager of the Pacific Tin Consolidated Corp.

James T. McDonald is working for the Bunker Hill and Sullivan Mining and Concentrating Co. at Kellogg, Idaho, as a surveyor.

Clarence O. Mittendorf is on an ECA mission to Turkey. He can be reached at Ankara in care of the American Embassy.

C. C. Huston

C. C. Huston, former head of the exploration department of Macassa Mines Ltd., has resigned from that post to enter into private consulting practice. His address is 1001-85 Richmond St., W., Toronto.

R. M. Mahoney

R. M. Mahoney is continuing his activities with the United States Vanadium Corp. as manager of industrial relations but has moved his headquarters to Bishop, Calif.

Ivan L. Nichols is working as a metallurgical trainee for the U. S. Smelting Refining and Mining Co. at Midvale, Utah. He had been with the Pacific Bridge Co. in Park City.

C. M. Peters, who left his post as geologist and chief engineer at the Neptune Gold Mining Co. after completing one year, is now working out of San Francisco for the firm of Dames and Moore, who do foundation engineering and soil mechanics. He is their geologist and job engineer on work that consists of testing the soil and formation for foundations of buildings, bridges, and dams.

R. G. Ponsford recently became a member of the Ponsford-Moos Equipment Co., El Paso. He was formerly with the Mine and Smelter Supply Co. and takes to his new post many years of experience specializing in mining, industrial, and shop equipment.

Burton M. Reynolds was appointed mining engineer, Rolla branch, Mining Division, Bureau of Mines, last November, going there from Idaho. He was formerly with the Bureau in College Park, Md. His present assignment is in Little Rock, Ark.

T. A. Rickard, of Victoria, B. C., has been appointed an honorary fellow of the Imperial College of Sciences. Most octogenarians are satisfied to sit back and let the world carry on by itself, but not Dr. Rickard. Last year he published "Historic Backgrounds of British Columbia," and recently his new book, "Autumn Leaves," has appeared.

Ernest R. Rodriguez is working as a mining engineer with the safety branch of the Bureau of Mines with headquarters at Phoenix, Ariz.

John A. Roos is working for the Baroid Sales Division of the National Lead Co. as a mining engineer. His address is Box 265, Belle Fourche, S. Dak.

John G. Reilly resigned as general manager of the Bayard, N. Mex., department of the United States Smelting Refining and Mining Co. on May 21. He will enter the consulting field and will continue to maintain his residence at 407 College Ave., Silver City, N. Mex. Mr. Reilly formerly was managing director of Cia. Real del Monte y Pachuca at Pachuca, Hidalgo, Mexico.

Joseph T. Roe is construction engineer for Dent and Russell Inc., Dantors division, mining, milling, and manufacturing, in Maupin, Oreg.

H. L. Roscoe, vice-president and general manager of Noranda Mines Ltd., who had been resident in Noranda since the beginning of operations, has moved to the head office in Toronto. **R. V. Porritt,** who has served the Company since 1926, for the last ten years as assistant general manager, was appointed manager.

Robert J. Rose has gone to the Union of S. Africa where he can be reached in care of the Messina Development Co., Messina, Transvaal.

Pierre Routhier, fellow of the University of Paris, former head of the geological mission of the office of the Recherche Scientifique Coloniale in New Caledonia, left New Caledonia recently. He and two associates will study the material collected there in the geological

laboratory of the Ecole Normale Superieure, 45 rue d'Ulm, Paris.

Larry Seaman, project manager for the Iron Mines Co. of Venezuela, a Bethlehem Steel Co. subsidiary, has changed his address from Caracas, Venezuela, to Guiria, Estado Sucre, Venezuela, where the Iron Mines Co. is building a port for the transshipping of Venezuelan iron ores.

Henry G. Schuring, formerly connected with La Luz Mines Ltd. at Siuna, Nicaragua, is now mill superintendent of the New Idria Honduras Mining Co., Santa Rosa de Copan, Honduras.

Charles E. Stott, formerly vice-president and general manager of Cia. Minera de Penoles and Cia. Metalurgica Penoles, subsidiaries of the American Metal Co., is at present located in Washington, D. C., as regional specialist with the strategic materials division of ECA, covering Africa.

J. A. Swart, who was general superintendent for the Raymond Concrete Pile Co., on their contract to build the Cardon refinery for the Shell Oil Co., has gone to Chuquicamata, Chile, as assistant job manager with Foley Hermanos on the construction contract to build a new sulphide plant for the Chile Exploration Co.

J. R. Sweet arrived in the States last August from Northern Rhodesia where for the past 4½ years he was in the service of the Roan Antelope Copper Mines, Ltd., Luanshya. He is now general manager for the Tungsten Mining Corp., Henderson, N. C. His residence address is 230 Virginia Ave., Henderson.

E. H. Thaete, Jr., has transferred his headquarters from New York to the New Orleans office of the Freeport Sulphur Co., 1804 American Bank Bldg.

E. L. Thomas, Jr., was graduated in mining engineering from the University of Alabama at the end of the last quarter and will be located in the Birmingham district with the Tennessee Coal, Iron, and Railroad Co.

David W. Tittman graduated from the Missouri School of Mines in January and was then employed by the St. Joseph Lead Co. as metallurgist in the ore dressing research laboratory. He is living at 207 E. School St., Bonne Terre, Mo.

Hale C. Tognoni is working at the Darwin Mines, Darwin, Calif. He had been a student at the University of Nevada.

Marvin J. Udy now spends half of his time with the Vanadium Corp. of America in the development of new processes for chromium and ferroalloys. At the same time he is acting as consulting engineer for the New Jersey Zinc Co. in the electric furnace smelting of Quebec ilmenite, and also for Fabrica Nacional de Carburo y Metallurgia of Santiago, Chile.

Gilfry Ward has been appointed vice-president in charge of sales of the American Manganese Steel Division of the American Brake Shoe Co. He will be located in Chicago Heights, Ill. With Brake Shoe since graduating from Yale in 1928 he has spent many years on both the East and West Coasts with the Amsco sales organization.

H. P. Willard has changed his address from 166 Tomb St., Tiffin, Ohio, to Gabbs, Nev.

J. P. Williams, Jr., chairman of the board of directors of the Koppers Co., Pittsburgh, retired from active management of the company in May. He remains a member of the board and will continue in his capacity as chairman of the board, as well as an adviser on special problems. Actively associated with the Koppers Co., or its predecessors, since 1920, he was manager of the Melcroft Coal Co. until Koppers absorbed it, was elected executive vice-president of Koppers in 1933, and became president in 1939.

John Worcester has been appointed production manager of the National Lead Co., S. A., with headquarters in Buenos Aires, Argentina.

Carl C. Youell is superintendent of the Jewell Ridge Coal Corp. at Oneida, Tenn.

• In the Metals Branch

© *Harris and Ewing*
Robert L. Baldwin

Robert L. Baldwin has been made assistant to **G. A. Wallerstedt,** western district manager for the Hardinge Co., York, Pa. He will assist in sales development, using the Hardinge office at 24 California St. in San Francisco as headquarters. Mr. Baldwin began his career in 1901 as a technician for the American Steel and Wire Co. in Cleveland. He joined the U. S. Steel Corp. in 1912 as a special representative in exploiting, licensing, and selling the Heroult electric steel furnace. When the Heroult basic patent expired in 1920 he joined the Republic Carbon Co., which was acquired fourteen years later by the National Carbon Co. He became sales development manager of the electrode division of that organization, retiring from that post this year to join the Hardinge organization.

Thomas E. Barlow, formerly on the staff of Battelle Memorial Institute, is now sales manager for Eastern Clay Products, Inc., Jackson, Ohio.

Joseph J. Brugman is no longer employed by Idaho Smelting Inc. He is now with the Morley Magnesium Foundries, Box 628, Renton, Wash., as metallurgical superintendent.

Thornton C. Bunch has transferred to Vallejo, Calif., where he is foundry superintendent at the Mare Island Naval Shipyard. He had been working at the Navy Yard at Pearl Harbor.

J. E. Burke, formerly at the University of Chicago, has recently joined the Knolls Atomic Power Laboratory at the General Electric Co. in Schenectady as a research assistant. His new home address is R. D. 1, Ballston Lake, N. Y.

Hans I. Elvander, Box 3616, Degerfors, Sweden, is assistant to the general superintendent of Degerfors Jernverks AB.

Matthew A. Hunter is retiring as dean of faculty after forty years of service at Rensselaer Polytechnic Institute, Troy, N. Y. He joined the faculty in 1908 as a professor in electrochemistry and has served as the head of the departments of electrical engineering, physics, and metallurgical engineering. Dr. Hunter was born in Auckland, New Zealand, in 1878, received a B.S. and M.A. degree from Auckland University College and then went on to London for a doctor of science degree from University College. He continued his studies at the University of Gottingen, Germany, at the Sorbonne in Paris, and the Techniche Hochschule at Karlsruhe, and came to the States in 1905 to work in the General Electric research laboratory in Schenectady.

Thomas A. Jackson is engaged as

a metallurgist and representative for the Volcan Mines Co. at Mahr Tunnel, Peru.

Edward C. Keller, formerly plant metallurgist with the Duquesne Smelting Corp. at Pittsburgh, has joined the firm of K. Hettleman and Sons at Baltimore, Md., as assistant manager of the Dixie metals division.

George V. Luerssen, chief metallurgist for the Carpenter Steel Co., was presented with the first annual David Ford McFarland award by the Penn State Chapter of the ASM at a dinner meeting on May 12. This award is made annually to a Penn State metallurgist who is judged to have attained eminence in his profession so as to bring credit upon himself and his alma mater. Mr. Luerssen talked on iron-nickel alloys and emphasized the need for further metallurgical attention in this field.

Robert E. Mahr has resigned his job with Sylvania Electric Products Inc. and is now located with the Chrysler Corp., central engineering division, powdered metals lab. in Highland Park, Mich. He will be glad to hear from any friends at his home at 2360 Bacon Ave., Berkley, Mich., phone number Lincoln 2-8728.

Daniel J. Milevich is mechanical foreman in the open hearth department of the International Harvester Company's Wisconsin Steel Works at S. Chicago, Ill.

Martin S. Miller is research metallurgist in the research laboratory of the Crucible Steel Co. of America at Harrison, N. J.

Herbert E. Pagel is now in Birmingham, Ala., working for the Tennessee Coal, Iron and Railroad Co. as a laboratory assistant in the metallurgical department in the Fairfield sheet mill.

Clarence B. Randall was elected to the presidency of the Inland Steel Co. on April 27 to succeed **Wilfred Sykes,** who becomes chairman of the executive committee. Mr. Randall, who had been assistant to the president, was vice-president in charge of materials. Mr. Sykes advised stockholders that net income for the quarter ended March 31 amounted to $9,254,230 or $1.89 a share, compared with a net of $8,458,544 or $1.73 for the March quarter last year. Mr. Sykes reported that there is now "ample evidence" that the pent-up demand for steel following the war is being satisfied, and that Inland's and the industry's capacity will be more than sufficient to supply the needs of the country, even at maximum peacetime consumption.

L. F. Reinartz has been named assistant vice-president of the Armco Steel Corp. He will continue to manage the Middletown division of Armco and the company's coal mining division in West Virginia will report to him. Mr. Reinartz began his Armco career in 1909 as a chemist in the open hearth department after receiving a metallurgical degree from Carnegie Institute of Technology. He advanced from assistant superintendent to superintendent of the open hearth department at Middletown, to assistant general superintendent to works manager of East works and in 1938 to manager of the Middletown division.

F. W. Bremmer

F. W. Bremmer, for 25 years with the National Supply Co., has been elected vice-president in charge of manufacturing, a post which has been vacant since **Charles R. Barton** retired a year ago. Mr. Bremmer has been works manager of the Spang-Chalfant division's Ambridge plant since May, 1948. He was first employed by the Standard Seamless Tube Co. of Ambridge, Pa., and shortly after that company was acquired by Spang-Chalfant became assistant superintendent of the hot mills. Spang Chalfant was acquired by National Supply in 1930 and ten years later Mr. Bremmer was appointed works manager of the division's Etna, Pa., plant, a post he held until his appointment as works manager of the Ambridge plant last year.

Earl W. Ross, who had been with the Naval Shipyard in Brooklyn, N. Y., has gone to Teterboro, N. J., to work for the Bendix Aviation Corp.

Bruce M. Shields has changed his address from the U. S. Steel Corp. of Delaware, Pittsburgh, to the metallurgy department of the Carnegie-Illinois Steel Corp. South Works, 3426 E. 89th St., Chicago 17.

Eric G. Skarin is service metallurgist for the Ohio Ferro-Alloys Corp., Citizens Bldg., Canton 2, Ohio.

Cyril Stanley Smith, director of the Institute of Metals at the University of Chicago, was one of the principal speakers at the dedication of two new buildings on the campus of Illinois Institute of Technology on June 17. He lectured and led a discussion on the "Microstructure of Metals" at a symposium in the auditorium of the chemistry building, one of the two being dedicated. The other new structure is the metallurgical and chemical engineering building.

F. M. Stearn, formerly with the Appleby Frodingham Steel Co., is now assistant metallurgist in the process development department of Henry Wiggin & Co., Birmingham, England.

Ralph H. Sweetser writes from his new address, RFD 2, Portsmouth, N. H., that he spent four months in Ohio in the midst of the controversy on the "rubber conveyor belt system" from Lorain to East Liverpool, Ohio, for conveying iron ore from the Lake to the Ohio River and coal from the River to the Lake. Mr. Sweetser fails to see how this will help the steel industry and feels that it won't help the railroads. He has found quite an interest in sponge iron, but doesn't know whether it is because of the scarcity and high cost of blowing engines or because of the tests of the Bureau of Mines at Laramie, Wyo.

Elbert C. Troy, who was chief metallurgist for the Dodge Steel Co., is now foundry engineer for the National Engineering Co. He receives mail at 5 E. Broad St., Palmyra, N. J.

J. C. Warner, dean of graduate studies and head of the chemistry department at Carnegie Institute of Technology, has been elected vice-president and a member of the board of directors of the Electrochemical Society.

D. F. Zlatnik is plant superintendent for the Basic Reduction Co. on the hydrometallurgical extraction, recovery, and refining of lead and zinc. His mail goes to P. O. Box 92, Henderson, Nev.

• In Petroleum Circles

John A. Fraher, formerly with the Sinclair Prairie Oil Co., is now employed as a petroleum engineer by the Bureau of Mines, Box 621, Laramie, Wyo. He is working on secondary recovery problems in the Rocky Mountain era.

Earl G. Griffith, after a little over three years with the Mene Grande Oil Co. in the Maracaibo Lake basin, the last year and a half as resident geologist of the Bolivar Coastal fields, de-

cided that it was time to put in a "contract" in the U. S. Moreover he and his wife wanted their son to be born in the States and enjoy the advantages of good medical care. Mr. Griffith arrived home 24 hours prior to his son's birth, which was pretty close timing. At present he is a petroleum geologist with The Texas Co. in the Montana district. He is living in Lewistown, Mont., and thinks it good country, with lots of hunting and fishing.

James W. Hepburn recently received appointment as assistant manager of the vertical turbine pump division of the Worthington Pump and Machinery Corp., Harrison, N. J. Mr. Hepburn set up his headquarters at the Corporation's Denver Works early in May, where he will be responsible for customer relations in the sale of vertical turbine pumps in the territories west of the Mississippi, including Chicago, St. Paul, and New Orleans. Mr. Hepburn was graduated from the engineering school of the University of Utah in 1929 and joined Worthington that same year as a sales engineer. In 1943 he was made district manager of the El Paso office, and since 1945 has been in the reciprocating pump division at the Harrison Works.

Michel J. Pagezy, a French student who had been studying at the Missouri School of Mines, has been in training as a petroleum engineer in production with the Sinclair Wyoming Oil Co. He expected to return to France in July to offer his professional services to the French petroleum industry.

Robert H. Parks has moved to San Antonio, Texas, and represents the Sunray Oil Corp. on the Seeligson Engineering Committee. His address is Transit Tower, San Antonio.

C. Sheldon Sharp has gone to Dhahran, Saudi Arabia, where he will be employed as a geophysicist working with gravity exploration for the Arabian American Oil Co. For the past ten years he had been working for the Brown Geophysical Co. on gravity surveys.

J. H. Sidwell has changed his address from the Union Tank and Supply Co., Tulsa, to the Hiawatha Oil and Gas Co., Milan Bldg., San Antonio, Texas.

M. H. Stekoll informs us that the main office of the Stekoll Petroleum Co. is now located at 1700 M&W Tower Bldg., Dallas. He has recently moved from Independence, Kan., where the Company, which is engaged in the oil producing business, has several waterflood operations.

Munsey W. Waters, engineer for the George E. Failing Co., manufacturer of rotary drilling equipment, can be reached at 1001 Sunset Drive, Enid, Okla.

Bing Quai Yee is addressed at the exploration department of the Carter Oil Co., P. O. Box 120, Denver, Colo. He had been at Oklahoma University.

Robert W. Zwicky has the job of junior exploitation engineer with the Shell Oil Co. and receives his mail at 2436 Shakespeare, Houston, Texas.

Obituaries

CHASE SALMON OSBORN (Member 1916), former governor of Michigan, prospector, geologist, writer, and a man who helped create some of the history of his times, died in Poulan, Ga., on April 11, at the age of 89.

Mr. Osborn's Lincolnesque, self-made career began in an Indiana log cabin in 1860, and his first job was that of newspaper boy. By 1912 he had bought, published, and sold three mid-western newspapers. A penchant for hunting took him off on expeditions to the Canadian woods, and led to his discovery of the Michipicoten iron range and the Moose Mountain range in that country's northland, which discoveries brought him a considerable fortune. He was instrumental in the development of the Great Lakes region, and did much field work in the Lake Superior districts of Michigan, Wisconsin, Minnesota, and Ontario.

The efforts of "Uncle Chase" were not confined to the United States, however, as witness his discovery of the Kiruna and Luossavara deposits in Lapland, and other iron ranges in Africa, the Orient, and Latin America. His adventures in Madagascar were presented in his book "Madagascar, Land of the Man-Eating Tree," in 1924.

Mr. Osborn held no less than seven university degrees, although he had only that number of years of formal schooling. The degrees were honorary—honoring the man who was Michigan's governor from 1911 to 1913; who wrote one of the nation's first workmen's compensation laws; who was instrumental in drafting Theodore Roosevelt for the presidency; who founded the Michigan Fellowship in Creative Art; who headed the National Committee of Independent Voters for Roosevelt in the 1940 campaign; who knew nine Presidents, and gave away a fortune.

The list of organizations of which he was a member would fill most of this column. As an author, he wrote "The Andean Land"; "The Iron Hunter"; "The Law of Divine Concord"; "A Short History of Michigan"; and other volumes.

Perhaps he left a clue to the secret of his success. Someone once asked him what schools he had graduated from, to which he replied—"Big woods and mountains."

ANDREW MELLICK TWEEDY (Member 1914), mining engineer, and former director and general manager of the South American Development Co., died at San Angelo, Texas, on Jan. 6. He was 64 years old. Mr. Tweedy was a native Texan, but he came East to take his B.S. in mining engineering from the Columbia School of Mines in 1906. He worked for the American Pyrites Co. in Herman, N. Y., for two years, and then the next eight years found him employed in various Mexican mining camps. In 1916, he became resident manager for the South American Development Co. in Portovelo, Ecuador. Thirteen years later he was managing the company from its New York offices, and in 1935 became a director, continuing in that post until his retirement in 1943. His services were retained as a consulting engineer for the firm until the time of his death.

One of his noteworthy achievements was the placing of the old Zaruma operation on a profitable basis, and Mr. Tweedy's ability, vision, and understanding were well known to have played a major part in the solution of the many problems therein presented.

Necrology

Date Elected	Name	Date of Death
1948	Robert H. Bedford	April 26, 1949
1948	Charles A. Bruce	March 11, 1949
1892	William H. Corbould	March 16, 1949
1948	William J. Flori	May 7, 1949
1896	Robert H. Jeffrey	January 31, 1949
1920	Joseph P. Labaw	April 27, 1949
1909	James E. Little	May 24, 1949
1947	Leonard Lynch	Oct. 18, 1948
1890	James MacNaughton	May 26, 1949
1909	Charles Mentzel	June 1, 1949
1916	Hubert Merryweather	June 7, 1949
1912	William C. Phalen	May 27, 1949
1945	Russell E. Reilly	Unknown
1917	Chard O. Sanford	January 31, 1949
1945	George L. Smith	Unknown
1918	Philip S. Smith	May 10, 1949
1915	Walter Stalder	May 27, 1949
1938	Arthur B. Yates	May 10, 1949

Proposed for Membership

Total AIME membership on May 31, 1949, was 15,729; in addition 4348 Student Associates were enrolled.

In the following list C/S means change of status: R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

ARIZONA

Ajo — NEWETT, JOHN W. (M). Chief engineer, New Cornelia branch, Phelps Dodge Corp.

Globe—MELLUS, HERBERT HEATH. (C/S—J-M). Pit engineer, Inspiration Consolidated Copper Co.

Inspiration—PATE, MANOAH LASLEY. (C/S—J-M). Mining engineer, Inspiration Consolidated Copper Co.

Tucson — KUMKE, CHARLES AUGUST. (R-M). Mining engineer, Bureau of Mines.

ARKANSAS

Smackover — VESTAL, WILLIAM ARTHUR. (C/S—S-J). Petroleum engineer, Phillips Petroleum Co.

CALIFORNIA

Hollywood — OFFEMAN, RICHARD E. (M). Manager, Pacific Coast division laboratory, Baroid Sales Division, National Lead Co.

Los Angeles—HAYTHORNE, PERCY ALLEN. (M). Research engineer, supervisor of metallurgical research, Lockheed Aircraft Corp.

Riverside—NICKERSON, KENNETH WESLEY, JR. (C/S—S-J). Geologist, Kennecott Copper Corp.

Rodeo—MONFORT, JOSE VARGAS. (C/S—J-M). Smelter chemist, American Smelting and Refining Co.

San Carlos—HACK, WALTER LAWRENCE. (M). Chief metallurgist, Western Gold and Platinum Works.

Taft — HENDERSON, ALEXANDER DUNCAN, JR. (R,C/S—JA-M). Field superintendent, Stanolind Oil Co. of California.

COLORADO

Denver — UNDERWOOD, ERVIN EDGAR. (C/S—J-M). Graduate student, MIT.

Leadville—SCHULTZE, JOHN FREDERICK. (C/S—S-J). Metallurgist, Leadville milling unit, American Smelting and Refining Co. YOUTZ, ROBERT CHARLES. (C/S—S-J). Mine sampler, Resurrection Mining Co.

ILLINOIS

Chicago—FERM, ERIC W. (M). Sales metallurgist, Miller & Co. MARTIN, HAROLD JOHN. (M). Sales engineer, Miller & Co.

Du Quoin—ALBON, DEAN ELLIOTT. (J). Chief engineer, Airmite-Midwest, Inc.

Wilmette — WARE, THOMAS MORROW. (M). Industrial engineer, International Minerals and Chemical Corp.

INDIANA

E. Chicago — BROWN, CALVIN CHARLES. (C/S—J-M). Metallurgist, Inland Steel Co. TATOUSEK, RICHARD JOSEPH. (C/S—J-M). Open hearth practice foreman, Inland Steel Co.

Fort Wayne — LAULETTA, PAUL ANDREW. (C/S—J-M). Metallurgical engineer, Joslyn Mfg. & Supply Co.

Hammond—BONICK, JAMES FRANCIS. (J). Metallurgist, Inland Steel Co.

LOUISIANA

New Orleans — BANKS, ROBERT TUNSTALL, JR. (M). Consulting engineer. GLENN, ALFRED HILL. (M). Consulting meteorologist, A. H. Glenn & Associates. SQUYRES, FRANK WILBUR. (AM). District representative, Eastman Oil Well Survey Co.

Shreveport—FENWICK, DICK TIMS. (M). Production supt., Southern Production Co. REEVES, JAMES NEAL. (J). Geological scout, Pan American Production Co.

MARYLAND

Silver Spring—BACON, JAMES EVERETT. (M). Technical counselor.

University Park—BARRY, ANTHONY J. (M). Mining engineer, Research, Bureau of Mines.

MASSACHUSETTS

Cambridge — GAINES, RICHARD VENABLE. (C/S—J-M). Postgraduate student, Harvard University. JAFFE, LEONARD DAVID. (C/S—J-M). Chief, physical metallurgy section, Watertown Arsenal. MEAD, JUDSON. (C/S—S-M). Geophysicist, U. S. Smelting Refining & Mining Co.

Newton — MARTIN, JAMES LEO. (C/S—J-M). Director-laboratory, Watertown Arsenal. PITTS, PARKER DESALES. (J). Geologist, F. D. Pitts Co.

Springfield — MORRIS, ALBERT WOOD. (R-M). Research engineer, director of research, Moore Drop Forging Co.

Wellesley Hills—STOKES, CHARLES ANDERSON. (M). Director of research and development, Godfrey L. Cabot, Inc.

MICHIGAN

Ann Arbor—REYNOLDS, EDWARD EVANS. (J). Research associate, Engineering Research Institute, University of Michigan.

Ishpeming—RIBOTTO, PETER PAUL. (C/S—J-M). Chief engineer, Inland Steel Co.

MINNESOTA

Buhl—SCHEUER, CHARLES HENRY. (M). Chief engineer, W. S. Moore Co.

MISSISSIPPI

Washington—DONALDSON, ROBERT WARREN. (J). Petroleum engineer, The California Co.

MISSOURI

Kirkwood — MOORE, THOMAS I. (C/S—J-M). Assistant general superintendent, American Zinc Co. of Illinois.

Rolla — DAVIS, CHARLES MALCOLM. (M). Assistant professor of petroleum engineering, mining department, Missouri School of Mines.

St. Louis — BURKHARDT, FRED ROLLAND. (M). Civil engineer, Sinclair Coal Co.

MONTANA

East Helena — LANE, STANLEY MARTIN. (R,C/S — J-M). Assistant superintendent, American Smelting & Refining Co.

NEVADA

McDermitt—HAAS, VERNE P. (M). General superintendent, Cordero Mining Co.

Pioche — McINTYRE, E. STEELE. (C/S—J-M). Mine engineer, Combined Metals Reduction Co.

NEW JERSEY

Freehold — REICHARD, EDMUND CARL. (C/S—J-M). Research metallurgist, American Smelting & Refining Co.

Union — WALLACE, EDWARD MORRIS. (C/S—J-M). Chief engineer, Vulcan Safety Razor Corp.

NEW MEXICO

Hanover — CASON, CARROLL C. (C/S—S-J). Engineer, Peru Mining Co.

Hobbs — BRIGHT, WAYNE R. (R,C/S—S-M). Petroleum engineer, Stanolind Oil & Gas Co. COURTRIGHT, RAYMOND ORLAND, JR. (M). Field engineer, Stanolind Oil & Gas Co.

NEW YORK

Floral Park — BEYER, ARTHUR JONES. (C/S—J-M). Metallurgical engineer, Atomic Energy Commission.

New York—KAHN, WALTER CHARLES, JR. (C/S—J-M). Assistant technical director, N. Y. Testing Laboratories, Inc. REED, HARLOW JOHN. (C/S—J-M). Metallurgical engineer, Singmaster & Breyer. SCARBOROUGH, FRANK GRIFFIN. (C/S—S-J). Engineer officer, fleet training group, U. S. Navy, Guantanamo Bay. WANG, KUNG-PING. (R,C/S—S-M). Specialist, foreign minerals, Bureau of Mines. WAYLAND, RUSSELL G. (C/S—J-M). Special adviser, combined coal control group, OMGUS.

Schenectady — GEISLER, ALFRED HOLLIS. (C/S—J-M). Research associate, General Electric Co.

NORTH CAROLINA

Charlotte — CAMPBELL, JAMES EDWARD. (C/S—J-M). Chief smoke abatement engineer, City of Charlotte, N. C.

Raleigh — BROADHURST, SAMUEL DAVIS. (AM). Assistant state geologist, State of North Carolina.

OHIO

Cleveland—LYMAN, TAYLOR. (C/S—J-M). Associate editor, *Metal Progress* and editor, *Metals Handbook*, ASM.

Columbus—RABB, DAVID DANIEL. (C/S—J-M). Research engineer, Battelle Memorial Institute.

Youngstown — SPEER, EDGAR BOYLE. (M). Superintendent, Bessemer department, Carnegie-Illinois Steel Corp.

OKLAHOMA

Enid — WATERS, MUNSEY W. (C/S—AM-M). Engineer, George E. Failing Supply Co.

Tulsa—STINSON, JAMES ALBERT. (M). Petroleum engineer, Stanolind Oil & Gas Co.

PENNSYLVANIA

Aliquippa—KELLER, ALONZO CARROLL. (M). Superintendent, open hearth & Bessemer, Aliquippa works, Jones & Laughlin Steel Corp.

Butler — PARKER, HAROLD MERRITT. (M). Open hearth superintendent, Armco Steel Corp.

Latrobe—FLETCHER, STEWART G. (C/S—J-M). Chief metallurgist, Latrobe Electric Steel Co.

New Kensington—PHILLIPS, GLEN L. (C/S—J-M). Operating engineer, Aluminum Co. of America.

Philadelphia — FAY, MERVIN A. (C/S—J-M). Ceramic engineer, General Refractories Co.

Pittsburgh — BROWN, BENJAMIN FLOYD. (C/S—J-M). Research assistant, metals research laboratory, Carnegie Institute of Technology. DILLON, HERBERT GEORGE. (M). Sales manager, Heyl & Patterson, Inc. ERKUN, NEVZAT MEHMET. (C/S—S-J). Metallurgist, Pittsburgh Forgings Co. PETTIGREW, DAVID WEBB, JR. (C/S—S-J). Research engineer, research laboratory, Aluminum Co. of America.

Plymouth—BIRD, MORGAN, JR. (J). General manager, Kingston Mining Corp.

Riegelsville — ADAMS, JOHN H. (C/S—S-AM). Geologic field assistant, U. S. Geological Survey.

Rimersburg — WALKER, JOSEPH LAWRENCE, JR. (C/S—S-J). Resident mining engineer, Rimersburg Coal Co.

State College—LECZNAR, FRANCIS JOSEPH. (M). Assistant professor, Academy of Mining in Krakow.

TENNESSEE

Knoxville — BERGMAN, GEORGE WALTER. (M). District manager, Joy Mfg. Co.

TEXAS

Conroe—HAINES, FRANK SAMUEL, JR. (C/S—S-J). Field engineer, The Texas Co.

Corpus Christi — MONTGOMERY, JAMES M. (M). Tools superintendent, Halliburton Oil Well Cementing Co.

Dallas — WISENBAKER, JOHN D. (M). Manager of operations, Core Laboratories, Inc.

Denver City — CAWLEY, AARON. (C/S—S-J). Engineering trainee, Honolulu Oil Corp.

El Paso—CHRISTENSEN, FRANK J. (M). Construction engineer, district manager, Stearns-Roger Mfg. Co.

Graham — WESTFALL, MILLARD FRANK. (J). District petroleum engineer, Cities Service Oil Co.

Houston — JONES, KENNETH E. (M). Division engineer, Baash-Ross Tool Co. WEAVER, EARL MARSHALL. (M). Vice-president, Herb J. Hawthorne, Inc. WESTBROOK, M. ALLEN. (M). Supervisor, Houston area production laboratory, Shell Oil Co.

Lubbock—ENGLE, DONALD DAVID. (J). Junior petroleum engineer, Stanolind Oil & Gas Co. HINKLE, HENRY WILLIAM. (J). Equipment engineer, Stanolind Oil & Gas Co. THOMPSON, LEWIS MARTIN. (J). Petroleum engineer, Stanolind Oil & Gas Co.

McAllen — McGEE, CHARLES J. (C/S—S-J). Engineer and branch office manager, Petroleum Service Co.

Midland — FORGERSON, CARL DAVIS. (J). Junior petroleum engineer, Stanolind Oil & Gas Co. MONTGOMERY, WILLIAM JEFFERSON. (C/S—S-J). Lawyer, Klapproth & Hamilton. WRIGHT, THOMAS RUSSELL. (R,C/S—S-J). Junior petroleum engineer, Stanolind Oil & Gas Co.

North Cowden — WILLIAMSON, JACK WOODROW. (M). Petroleum engineer, Continental Oil Co.

Odessa — CAMPBELL, CHARLES CLARK. (M). Production foreman, Atlantic Refinery Co. MASSEY, WILLIAM PATRICK. (M). Sales engineer, Garrett Oil Tools, Inc. RIKE, JAMES L. (J). Junior district petroleum engineer, Humble Oil & Refining Co. ROBERTSON, FRANK LINDSAY. (J). Junior production engineer, Atlantic Refining Co. SMITH, EARL B. (AM). Sales engineer, Garrett Oil Tools, Inc.

San Antonio—TALIAFERRO, SCOTT LEETH. (J). Junior petroleum engineer, Stanolind Oil & Gas Co.

Tyler — DeLONG, JACK MYLER. (AM). Geologist, Stanolind Oil & Gas Co.

Yorktown — SUTHERLAND, JOHN WELSEY, JR. (R,C/S—S-J). District engineer Sunray Oil Corp.

UTAH

Hiawatha—JACKSON, THOMAS C. (M). General superintendent, U. S. Fuel Co. RAMEY, RUSSELL WAYNE. (R,C/S—S-M). Assistant to general superintendent, U. S. Fuel Co.

VIRGINIA

Arlington — MATTHEWS, ALLAN FREEMAN. (C/S—J-M). Editor, Minerals Yearbook, Bureau of Mines.

WASHINGTON

Vancouver—WILTSCHKO, WILLIAM WESLEY. (C/S—J-M). Metallurgist, Aluminum Co. of America.

WEST VIRGINIA

Fairmont—FOLK, WILLIAM RICHARD. (J). Field representative, mechanical goods division, Goodyear Tire & Rubber Co.

Gary — GILLISON, GEORGE THOMAS. (M). Ventilation engineer, U. S. Coal & Coke Co.

WYOMING

Casper—BURBACK, FRASER MERRITT. (R,C/S—S-J). Assistant engineer, production department, General Petroleum Corp. CONGDON, CLYDE GLOVER. (R,C/S—S-M). District engineer, Wyoming district, The Texas Co. DAVIS, JOHN JOSEPH. (J). Assistant to petroleum engineer, Chemical & Geological Laboratories, Inc. HOENSHELL, DAVID TOBY. (M). District engineer, General Petroleum Corp.

ALASKA

Anchorage — STRANDBERG, EDWARD ODIN. (AM). Mine superintendent, Strandberg & Sons. STRANDBERG, WILLIAM J. (AM). Mine superintendent, Strandberg & Sons.

ONTARIO

Orillia—MacFARLANE, JOHN KENNETH. (R,C/S—S-M). Efficiency engineer, International Nickel Co.

Port Colborne — LEWIS, WILLIAM JAMES CHARLES. (C/S—J-M). Metallurgist, Canadian Furnace, Ltd.

Virginiatown—BROWNBILL, HERMAN FREDERICK. (M). General superintendent, Kerr-Addison Gold Mines, Ltd.

NEW BRUNSWICK

Sussex — HALCROW, ALEXANDER FOCH. (C/S—S-M). Exploitation engineer, Shell Exploration New Brunswick, Ltd.

BOLIVIA

Pulacayo—TISO, PILADE ARTURO. (J). Petrographer and mining geologist, Cia. Huanchaca de Bolivia.

VENEZUELA

Caracas — MASHMEYER, GORDON WILLIAM. (M). District production foreman, Socony-Vacuum Oil Co. of Venezuela. WILKIE, SYDNEY KERR. (J). Mud engineer, Socony Vacuum Oil Co. of Venezuela.

Maracaibo—CASAS, JULIO CESAR. (C/S—S-J). Petroleum engineer, Creole Petroleum Corp.

DENMARK

Copenhagen—ENGEL, NIELS NIKOLAJ. (M). Professor of physical metallurgy, Royal Technical University of Copenhagen.

ENGLAND

Didcot, Berkshire — PATCHING, STANLEY WILLIAM FREDERICK. (M). Principal scientific officer, mineral dressing group, Ministry of Supply.

FRANCE

Montpellier — HERRENSCHMIDT, JEAN DIDIER. (M). Chief petroleum engineer, Société Nationale des Pâtroles du Languedoc Mediterranéen.

Paris — WOLFE, SIDNEY PAUL. (AM). Installation engineer, Joy Mfg. Co.

GERMANY

Helmholtzstr — GUTACKER, WILHELM BRUNO. (M). Consulting engineer.

NORWAY

Jorpeland — GJEDEBO, FINN. (M). Work manager, Staranger Electro-Staalverk A/S.

Oslo—HANSSON, PER. (M). Metallurgist, Christiania Spigerverk.

INDIA

Banaras — SWAMY, KOLAGOTLA BHIMESWARA. (M). Professor of mine surveying, Banaras Hindu Univ.

Madras—GOPALAKRISHNAIAH, B. (C/S—S-M). Assistant professor of chemistry, education department, Govt. of Madras, India.

VICTORIA

Melbourne—CLARK, GORDON COLVIN LINDESAY. (M). Technical managing director, Western Mining Corp., Ltd.

BORNEO

Sarawak—ROE, FRANK WALTON. (M). Chief geologist, British Territories in Borneo.

STUDENT ASSOCIATES

Elected May 18, 1949

Robert A. Coleman.....Texas A&M
Cliffort Ray Hudson.....Okla. A&M
Clement Peter Kuzma..Univ. Pittsburgh
David William Levinson..Ill. Inst. Tech.
Clifton M. McDaniels..Colo. Sch. Mines
John Flett Rollins.....Univ. N. H.

Elected June 15, 1949

Hassan Hassny Aboul-Seoud Univ. Calif.
James Franklin Addington, Jr., La. State Univ.
Bernard Allen Aggers....Univ. S. Calif.
Joseph Ross Anderson.....Univ. Minn.
Craig Trenary Anneberg....Univ. Idaho
T. S. Ary.....Stanford Univ.
Howard Eden Banta..Mont. Sch. Mines
Perry Newland Barham Tex. Tech. Coll.
Douglas Dale Barman..St. Louis Univ.
Dan Alan Bee.....Texas Tech. Coll.
Isadore Binder.....Wayne Univ.
Clarence H. Blackburn.....Univ. Okla.
Louis David Blom.....La. State Univ.
Keith Edgar Bohrer.....Univ. Kans.
Carl Ferdinand Brass, Jr. Univ. Pittsburgh
Robert Wayne Buel..Mo. Mines & Met.
Kenneth Wayne Bull.....Univ. Okla.
John George Bunker.....Univ. Wis.
Rex Harold Byers, Jr...La. State Univ.
Fred Markham Carroll..Univ. S. Calif.
Ralph Edger Carter.....Univ. B. C.
Thomas Ford Clemens.....Univ. Nev.
Robert Chetham Cockrell...Univ. Ala.
Stanley Edgar Comstock....Univ. Wis.
George Denis Cordner..Univ. Melbourne
Neil Vernon Cottrell....Univ. S. Calif.
Robert Joe Cronk....Mo. Mines & Met.
Robert Earl Crowder....Univ. S. Calif.
Donald John Cunningham...Univ. Nev.
Donald Peter Dampf..Mo. Mines & Met.
Elbert D. Diebold.....Univ. S. Calif.
Russell Ervin Diefenbach Mo. Mines & Met.
John M. Donna.....St. Louis Univ.
Wesley Eckley.....St. Louis Univ.
George W. Edwards, Jr...St. Louis Univ.
Charles J. Eskridge, Jr.....Univ. Tulsa
Barry Louis Evans.....Univ. S. Calif.
Archie Pence Farr.....Univ. Texas
Tyler Aubrey Ferguson.Tex. Tech. Coll.
Frank Wilson Ficklin..Tex. Tech. Coll.
Calvin Leo Franke.....Univ. Okla.
Joseph Wincene Fusso..St. Louis Univ.
Walter James Gabriel (Rein.) St. Louis Univ.
Richard Edward Gaffney Mont. Sch. Mines
Reynold Merritt Gardner, Jr. Univ. Okla.
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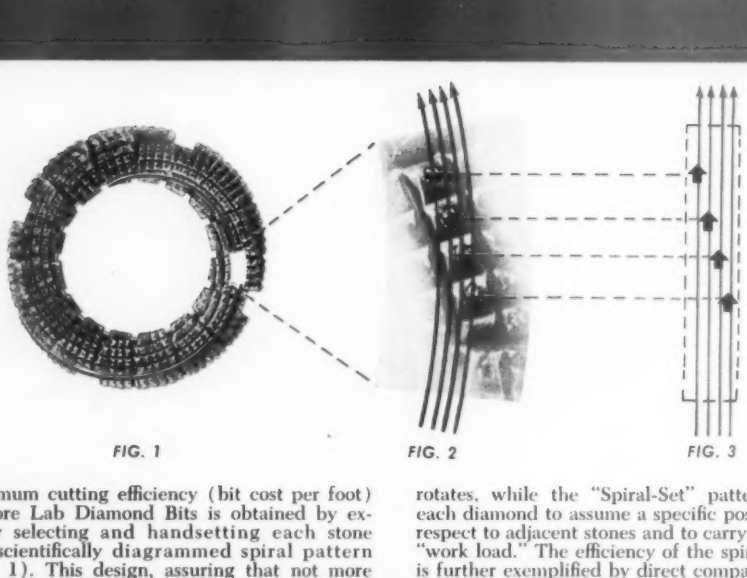

FIG. 1 FIG. 2 FIG. 3

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RESERVOIR PERFORMANCE OF A HIGH RELIEF POOL

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ABSTRACT

A method is presented for evaluating the effect of gravity drive upon the reservoir performance of a high relief pool. Conventional forms of reservoir analysis do not consider the alterations in the basic material balance data caused by gravity segregation of reservoir fluids. A procedure is outlined for structurally weighting physical and chemical data for use in the material balance equation. It is demonstrated how actual pool performance data can be utilized to evaluate the future reservoir performance of a gravity drive pool.

INTRODUCTION

Conventional reservoir engineering procedure is inadequate for the analysis of an oil pool which has considerable structural relief, steep dips, and good permeability development. In pools of this type, gravity drainage has an important part in the movement of oil to the wells and the effects of gravity on the overall pool performance should be included in any analysis of reservoir behavior. Many engineers have the opinion that the force of gravity in the movement of oil is not important until the later life of a pool.[1] Probably the basis for this belief is that gravitational effects may not be readily discernible until a pool is nearing depletion. This would be especially true for pools not having a high degree of structural relief and permeability development. Actually the effects of gravitational forces are at a maximum when the pool pressure is high, for during this period the hydrostatic head of the oil column is at a maximum and the viscosity of the oil is at a minimum.

Oil recoveries from pools having favorable gravity drive characteristics may equal or even exceed recoveries which might be expected from water displacement. Field evidence indicates that in some reservoirs gravity drive has resulted in recoveries greater than that which could have been expected from gas expansion or water drive.[2,3] Unfortunately, the possible effects of gravity drive on pool performance have been underestimated and other reasons have been sought to explain the high recoveries obtained. There are unquestionably many reservoirs to which the principles of gravity drainage can be effectively applied.

It is the purpose of this paper to illustrate one method whereby gravity drive is included in the reservoir analysis of an oil pool. A hypothetical pool, typical of many California reservoirs, is used as an example. As used in this paper, "gravity drive" is defined as the overall effect of gravitational influences on the recovery of petroleum from the reservoir; "gravitational segregation" as the gravity separation of oil and gas within the reservoir; and "gravity drainage" as the downward movement of oil as caused by the force of gravity.

SAND VOLUME DATA

Fig. 1 presents a structural contour map of the pool under study. Maximum closure is 1950 feet with dips on the south flank approaching 45°. The original gas-oil interface was set at −5200 feet. Average thickness of the producing sand was 200 feet.

For use in subsequent calculations in this paper, the pool was subdivided into 100-foot vertical increments and the sand-volume content of each increment was obtained. If the gross sand thickness is small, under 100 feet, the sand-volume content can be obtained by superimposing an isopachous map upon a structural contour map and planimetering the average thickness of each 100-foot increment. For sand thicknesses over 100 feet, one approach would be to construct a sufficient number of cross-sections of the pool from which the weighted sand-volume of each 100-foot increment could be obtained. Variations in the sand body with depth, as determined by core data, can also be included in the above process.

Table I presents a summary of sand-volume calculations, core data, and the original distribution of reservoir hydrocarbons in the pool. Fig. 2 illustrates the structural distribution of the sand-volume content. A total of 171,398 acre-feet is contained within the productive limits of the pool. Assuming an average porosity of 25% and an interstitial water content of 20%, the original hydrocarbon content was computed to be 227,075,000 barrels.

DEPTH-PRESSURE DATA

The determination of the initial vertical pressure arrangement in the pool is necessary for PVT and material balance calculations. Whenever sufficient data are available, a plot of pressure versus subsea depth of measurement should be made. From this plot a representative fluid pressure gradient can be established. Lacking sufficient initial pressure data, an initial pressure gradient may be estimated or calculated from available PVT data.

Manuscript received at Petroleum Branch Office September 3, 1948. Paper presented at Branch Fall Meeting in Los Angeles October 14, 1948.

[1] References are given at end of paper.

TABLE I

Summary of Sand Volume and Reservoir Oil Content

Interval	Acre-Feet	Cumulative Acre-Feet	Reservoir Oil	Cumulative Reservoir Oil
—5000 to —5100	13,615	13,615	Gas	Gas
—5100 to —5200	11,434	25,049	Gas	Gas
—5200 to —5300	7,478	32,527	11,602,865	11,602,865 bbls.
—5300 to —5400	6,635	39,162	10,294,866	21,897,731
—5400 to —5500	6,899	46,061	10,704,488	32,602,219
—5500 to —5600	6,991	53,052	10,847,236	43,449,455
—5600 to —5700	7,245	60,297	11,241,342	54,690,797
—5700 to —5800	7,245	67,542	11,241,342	65,932,139
—5800 to —5900	7,752	75,294	12,028,003	77,960,142
—5900 to —6000	7,752	83,046	12,028,003	89,988,145
—6000 to —6100	8,006	91,052	12,422,110	102,410,255
—6100 to —6200	8,260	99,312	12,816,216	115,226,471
—6100 to —6300	8,260	107,572	12,816,216	128,042,687
—6300 to —6400	8,767	116,339	13,602,877	141,645,564
—6400 to —6500	9,021	125,360	13,996,984	155,642,548
—6500 to —6600	9,528	134,888	14,783,645	170,426,193
—6600 to —6700	9,782	144,670	15,177,751	185,603,944
—6700 to —6800	10,289	154,959	15,964,412	201,568,356
—6800 to —6900	10,543	165,502	16,358,519	217,926,875
—6900 to —6950	5,896	171,398	9,148,234	227,075,109

Core Data

Porosity = 25%
Interstitial Water = 20%
Hydrocarbon Content = 1,551.6 Bbls. per Acre-Feet
Average Sand Thickness = 200 feet

TABLE III

Structural Weighting of PVT Data

Example for Datum Plane Pressure of 2660 p.s.i.a.

Interval	Reservoir Oil	Pressure	FVF	FVF x Res. O.	GORs	GORs x Res. O.
5200—5300	11,602,865	2,375	1.268	14,712	448	5,198
5300—5400	10,294,866	2,405	1.271	13,085	453	4,664
5400—5500	10,704,488	2,435	1.274	13,638	458	4,903
5500—5600	10,847,236	2,465	1.277	13,852	463	5,022
5600—5700	11,241,342	2,495	1.280	14,389	468	5,261
5700—5800	11,241,342	2,525	1.282	14,411	467	5,250
5800—5900	12,028,003	2,555	1.279	15,384	461	5,545
5900—6000	12,028,003	2,585	1.277	15,360	455	5,473
6000—6100	12,422,110	2,615	1.274	15,826	449	5,577
6100—6200	12,816,216	2,645	1.271	16,289	443	5,677
6200—6300	12,816,216	2,675	1.267	16,238	437	5,601
6300—6400	13,602,877	2,705	1.264	17,194	431	5,863
6400—6500	13,996,984	2,735	1.262	17,664	425	5,949
6500—6600	14,783,645	2,765	1.259	18,613	419	6,194
6600—6700	15,177,751	2,795	1.256	19,063	413	6,268
6700—6800	15,964,412	2,825	1.253	20,003	407	6,497
6800—6900	16,358,519	2,855	1.250	20,448	401	6,560
6900—6950	9,148,234	2,870	1.248	11,417	398	3,641
Total or Weighted	227,075,109	2,660	1.2665	287,586	437	99,143

Reservoir Oil = Subsurface barrels (Table I)
Pressure = Midpoint of interval, psia (Fig. 3)
FVF = Oil phase formation volume factor (Fig. 4)
GORs = Solution gas-oil ratio, cu. ft. per bbl. (Fig. 5)

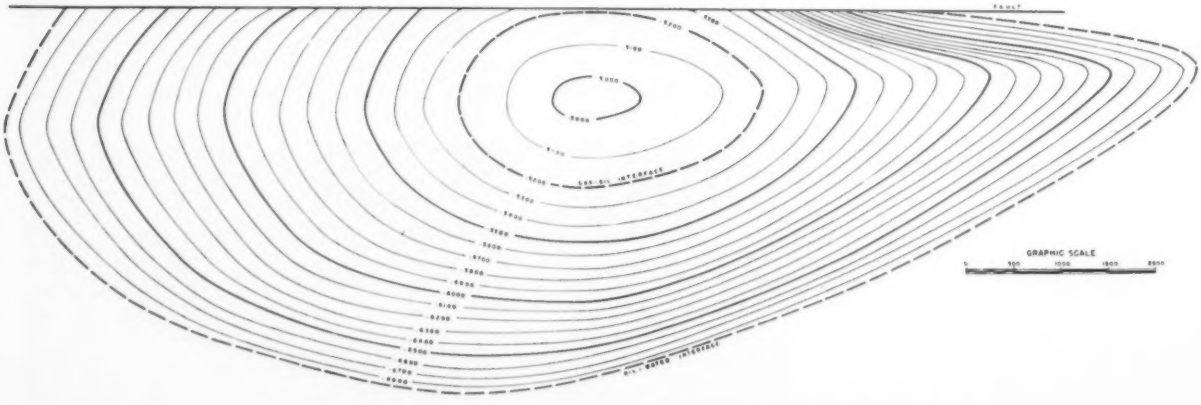

FIG. 1 — REPRESENTATIVE HIGH RELIEF OIL FIELD — CONTOURS ON TOP OF PAY.

The problem of establishing a standard pressure datum plane becomes exceedingly complex for high relief pools. Theoretically, the correct pool pressure at any given time is that pool pressure which represents the fluid mass within the producing reservoir. Initially this pressure would be the pressure at the volumetric mid-point of the reservoir. Oil and gas production from the pool, and the occurrence of gravity drainage in the pool causes a rearrangement of the structural distribution of the reservoir fluids. The continual downward migration of oil would necessitate a continual shifting of the pressure datum plane if a correct expression of pool pressure is to be maintained. Obviously the mechanics of determining the correct pressure datum position at succeeding time intervals would require the use of questionable assumptions as to fluid distribution in the reservoir. Secondly, most material balance data are dependent upon pressure and/or temperature. Changing the pressure datum position would require the continual alteration of basic PVT data which, from a practical standpoint, could nullify the value of the benefits to be gained.

The correction of well pressures to datum pressure in high relief pools requires an accurate determination of the fluid pressure gradient. In many cases it is necessary to correct pressures as much as 1,000 feet involving the addition or subtraction of 200 to 300 pounds to the bottom hole pressure. Through the application of conventional PVT calculations, it is possible to calculate the fluid density at any position on the structure and to predict the change in the density with pressure decline. However, before these refinements could be applied to pressure data, it would be necessary to know the reservoir fluid distribution surrounding each well. The difficulties to be overcome in determining fluid distribution nullify the value of the refinement. The use of a constant gradient correction factor is simple in application and accurately illustrates pressure differences between wells and surveys.

Therefore, it is believed that the most useable and reliable pressure data can be obtained by correcting bottom hole well pressures to a constant datum plane by the use of a constant fluid gradient correction factor. Weighted pool average pressures can be determined on an areal basis or a volumetric basis, as desired. Basic material balance and PVT

TABLE II

Calculated Composition of Well Effluent

	Mol Per Cent
Methane	43.3
Ethane	5.0
Propane	4.3
Iso-Butane	2.2
N-Butane	1.1
Iso-Pentane	1.2
N-Pentane	1.2
Hexanes, plus	41.7
	100.00

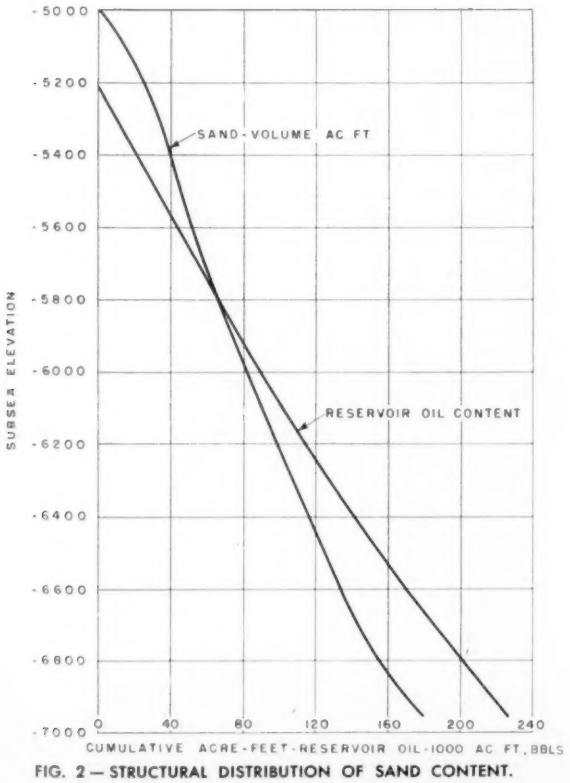

FIG. 2 — STRUCTURAL DISTRIBUTION OF SAND CONTENT.

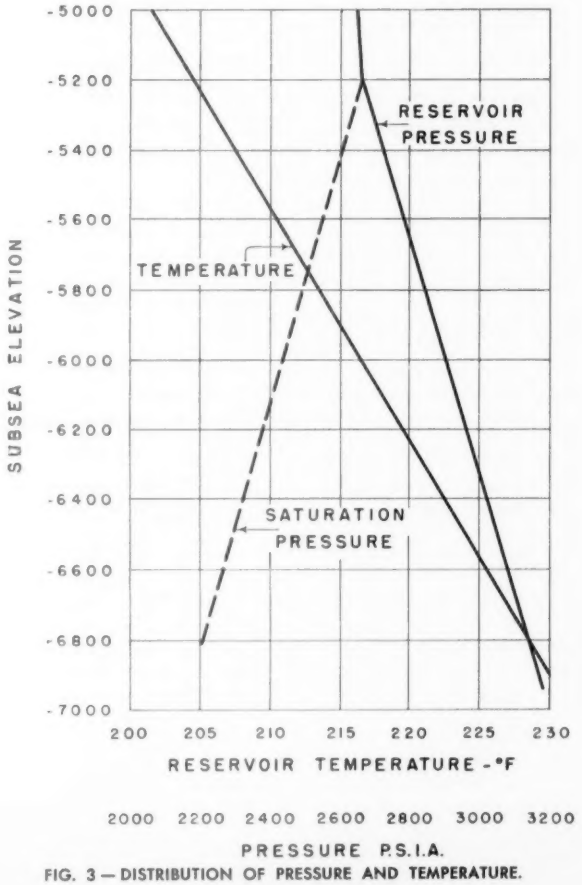

FIG. 3 — DISTRIBUTION OF PRESSURE AND TEMPERATURE.

data can be corrected to the same pressure base, allowing for rapid and straightforward performance calculations. Subsequent calculations in this paper will indicate how the small errors caused by the use of a constant pressure datum and pressure gradient are compensated.

PVT DATA

Pronounced pressure and temperature differences between the crest and flank of the reservoir due to high structural relief require a correction of all PVT data for structural location. If bottom-hole fluid samples are to be used, it is necessary to analyze the samples in the laboratory at two or more different temperatures so that the proper temperature corrections can be made. To illustrate the magnitude of temperature and pressure variations, Fig. 3 is presented, in which it is seen that for the pool under study, temperatures ranged from 201°F. to 231°F. and pressures from 2600 to 3200 pounds.

For thin sand reservoirs of low relief it is commonly accepted that the determined bubble point pressure will be constant for all locations in the pool. Also if the pool contains an initial gas cap, it is automatically assumed to have been initially gas saturated. For thick sand and/or high relief pools, the above conditions usually are not found. In pools of this type, the bubble point pressure may follow one of three forms:

TABLE IV

Influence of Reservoir Pressure Upon Reservoir Gas Composition

	Mol Per Cent at				
	2800 psia	2500 psia	2000 psia	1500 psia	1000 psia
Methane	87.70	87.85	87.22	85.92	83.54
Ethane	5.07	5.24	5.55	6.21	7.15
Propane	2.57	2.63	2.79	3.10	3.93
Iso-Butane	1.07	1.08	1.15	1.27	1.49
N-Butane	0.43	0.44	0.46	0.50	0.60
Iso-Pentane	0.39	0.39	0.41	0.45	0.52
N-Pentane	0.33	0.33	0.34	0.38	0.44
Hexanes Plus	2.44	2.04	2.08	2.17	2.33
	100.00	100.00	100.00	100.00	100.00

Temperature = 220° F.
Molecular Wt. Hexanes plus = 120.

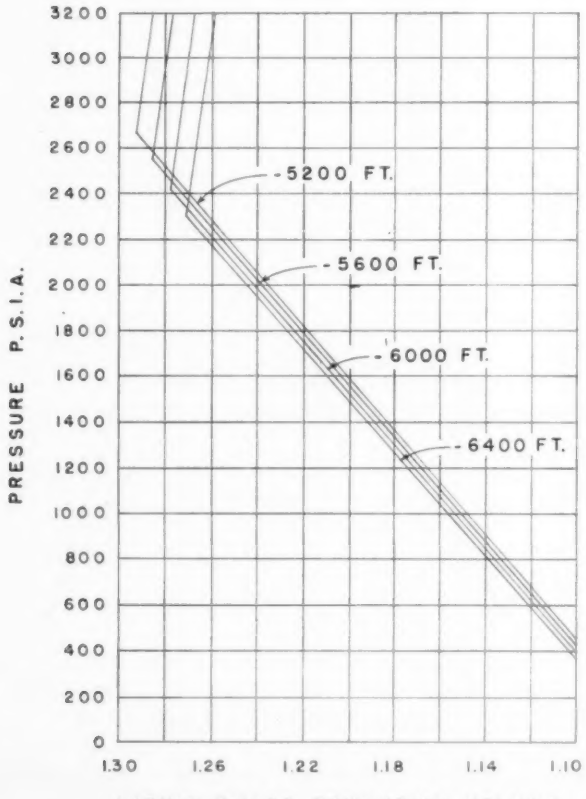

FIG. 4 — OIL SHRINKAGE.

TABLE V

Summary of Relative Volume Factor of Oil and Original Solution Gas — u

Pressure	Weighted For Structure	Weighted For Field Performance
2960	1.0000	1.0000
2860	1.0018	1.0017
2760	1.0041	1.0041
2660	1.0068	1.0066
2460	1.0162	1.0159
2260	1.0338	1.0325
2060	1.0633	1.0568
1660	1.1787	1.1390
1400	1.2950	1.2270
1000	1.6270	1.4620
800	1.9470	1.6620
600	2.4100	1.9780

Pressure = p.s.i.a. at —6135 ft. datum.

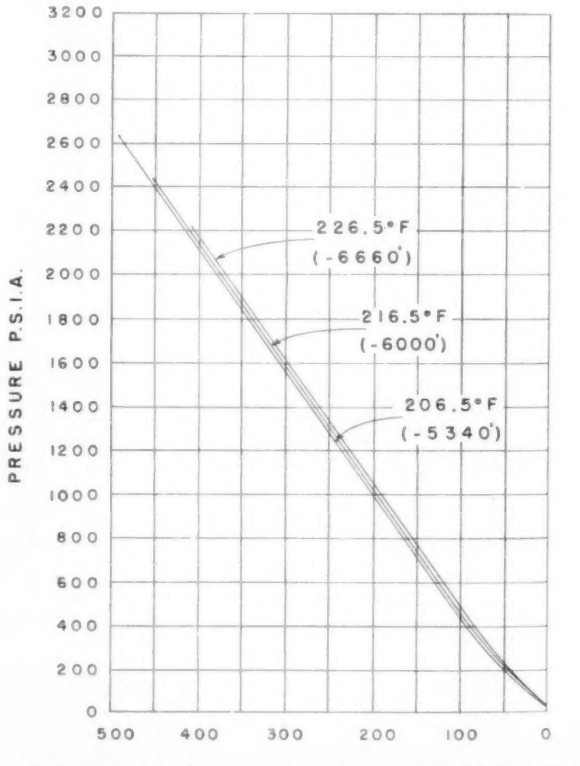

FIG. 5 — SOLUBILITY DATA.

1. The bubble point pressure at any structural position is equal to initial pressure existing at that depth. Pools of this type can be classified as completely gas saturated.

2. The bubble point pressure is equal to the existing pressure at one point on the structure. Pools of this type can be classified as both gas saturated and undersaturated, as it is conceivable to have the bubble point pressure equal to the initial pressure existing at some point below the crest of the structure, in which case all elevations about this point would be gas saturated and all points below would be undersaturated.

3. The bubble point pressure would decrease with depth. Pools of this type can also be classified as either gas saturated or undersaturated, depending upon the structural location of the maximum saturation pressure.

Experience to date indicates that the majority of high relief pools are of Type 2 or exhibit a constant bubble point pressure regardless of depth.[5] If free gas exists in the pool in the form of a gas cap, the oil at the gas-oil interface would be gas saturated but due to the degree of structural relief present, the oil below the interface would be undersaturated. This condition has been observed in several fields in California and may be explained by secondary movement of the structure after the oil was in place. This condition plus the existence of a tilted water table would indicate that complete reservoir equilibrium had not been attained at the time of discovery of the pool.

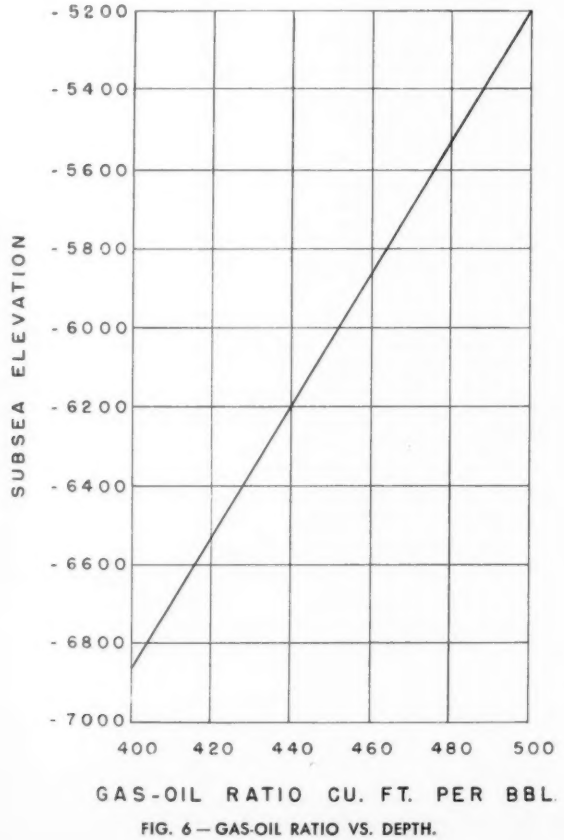

FIG. 6 — GAS-OIL RATIO VS. DEPTH.

There are field data[6] and analytical calculations[7] indicating the existence of Type 3 pools in California. The presence of a decreasing bubble point pressure with depth is evidenced by a decrease in produced gas-oil ratio with depth. Usually oil gravities will be lower on the flank wells.

Conventional procedure can be followed for performance calculations on Type 1 and Type 2 pools, once the bubble point pressure has been established. Calculations on Type 3 pools are more involved because of the variations in saturation conditions. The pool example of this paper was assumed to be of Type 3 characteristics with a bubble point pressure distribution as illustrated by Fig. 3. As shown by Fig. 3, the bubble point pressure decreases from 2660 psia at the gas-oil contact of −5200 feet to 2160 psia at the water-oil contact of −6950 feet.

To determine the effect of structural relief upon the PVT data, a representative vertical distribution of oil and gas samples should be obtained. Lacking this type of information, initial well gas-oil ratios and oil gravities may be correlated by the Standing[4] method to obtain bubble point pressures.

In Table II is presented the hydrocarbon analysis of the well stream effluent as calculated from a recombination of surface oil and gas samples. In Figs. 4 and 5 are presented oil shrinkage and solubility data for the pool under study. Fig. 6, gas-oil ratio versus depth, and Fig. 7, bubble point formation volume versus gas-oil ratio, are calculated from the data of Figs. 4 and 5. Fig. 8 presents oil and gas relative volume data as referred to bubble point oil, also plotted for various structural depths.

Before the above data can be readily applied in pool calculations it is necessary, for each item, to combine the variations due to structural depth into one composite curve which will represent the entire pool behavior. This procedure eliminates the cumbersome and intricate task of performing balance calculations on each vertical 100-foot block and will give results within the accuracy of the basic data. One method of calculating weighted PVT curves is illustrated in Table III in which the structural distribution of reservoir oil, as presented in Table I, is used as the basis of weighting the individual component curves.

Fig. 9 presents the resultant weighted pool shrinkage and solubility curves as calculated by the above procedure. Initial values calculated were 441 cu. ft. per barrel for solution gas-oil ratio and 1.2646 for reservoir oil formation volume factor —both values for the initial pressure of 2960 psia at the −6135 foot datum.

RESERVOIR GAS DATA

The method presented by Brown[8] was used to calculate the gas compressibility factor with one addition, and that was to include in the computations the changes in composition of the reservoir gas due to pressure decline. Brown's method assumes the composition of the reservoir gas will remain constant with reduction in pressure. However, as the composition does change,[7] as illustrated by Table IV, the effect of these changes should be included in the compressibility calculations.

Computations of the gas conversion or v factor were made in the conventional manner utilizing the above discussed gas compressibility factors. Due to the higher structural location and corresponding lower temperature of the gas cap, it was necessary to calculate a separate gas conversion factor for the cap gas. In Fig. 10 are presented v factor determinations for the oil zone gas and cap gas expressed in terms of pool datum pressure. Also on Fig. 10 are presented the results of the compressibility factor calculations. Utilizing the data of Fig. 10 and the sand volume content of the gas cap as presented in Table I, the original volume of the gas cap was calculated to be 35,000,000 Mcf. at standard conditions.

EFFECT OF GRAVITY ON POOL PERFORMANCE

It is pertinent at this time to discuss briefly the reasons why direct applications of conventional material balance equations cannot be applied to high relief pools. The material balance approach assumes the entire pool will follow the behavior represented by a sample increment of fluid which remains in its original reservoir position and environment. The physical properties of this sample can be accurately determined by laboratory procedure. However, in the presence of steep dips, high relief, and good permeability development, gravity segregation alters the original reservoir environment of the sample increment.

Actual pool performance is the best indicator that gravity segregation is occurring in a high relief pool. A study of the gas-oil ratio history of individual wells in a pool will indicate whether or not segregation of oil and gas is occurring. The structurally lower wells will exhibit a decreasing gas-oil ratio trend with time, while the crestal wells will prematurely go to gas. Theoretical calculations performed on gas drive pools indicate a definite upward trend in gas-oil ratios should occur as the pool liquid saturation approaches 89%. Actual performance data on gas drive pools indicate that this "gas

TABLE VI

Summary of Material Balance Data

P	FVF	GOR_s	u	$u-u_o$	v_o	v_g	F
2800	1.267	440	1.2680	0.0034	0.001074	0.00117	37,900
2600	1.265	434	1.2755	0.0109	0.001156	0.00124	39,580
2400	1.260	421	1.2897	0.0251	0.001253	0.00137	39,900
2200	1.251	400	1.3125	0.0479	0.001370	0.00151	39,350
2000	1.238	371	1.3486	0.0840	0.001513	0.00171	39,000
1800	1.221	337	1.3949	0.1303	0.001692	0.00200	37,700
1600	1.204	302	1.4638	0.1992	0.001919	0.00233	36,200
1400	1.186	268	1.5517	0.2871	0.002215	0.00277	34,050
1200	1.169	232	1.6807	0.4161	0.002612	0.00331	31,650
1000	1.151	197	1.8488	0.5842	0.003169	0.00396	29,050
800	1.134	160	2.1018	0.8372	0.004017	0.00480	25,750
600	1.116	125	2.5014	1.2368	0.005436	0.00600	22,450
400	1.099	90	3.0856	1.8210	0.008282	0.00828	16,250
200	1.081	52	4.2048	2.9402	0.016856	0.01686	9,320
100	1.070	26	5.2860	4.0214	0.033986	0.03399	5,100

P = Pressure at —6135 ft. p.s.i.a.
FVF = Oil phase formation volume factor.
GOR_s = Solution gas-oil ratio, cu. ft. per barrel.
u = Reservoir volume of one barrel stock tank oil and original solution gas at reservoir pressure.
v_o = Reservoir volume of free gas in oil band, bbls./std. cu. ft.
v_g = Reservoir volume of free gas in gas cap—bbls./std. cu. ft.
F = Gas-oil ratio conversion factor—bbl/bbl reservoir conditions to cu. ft. per bbl. std. conditions.
r_o = Original solution gas-oil ratio = 441 cu. ft. per barrel.
v_g = Original v_g factor = 0.00116.

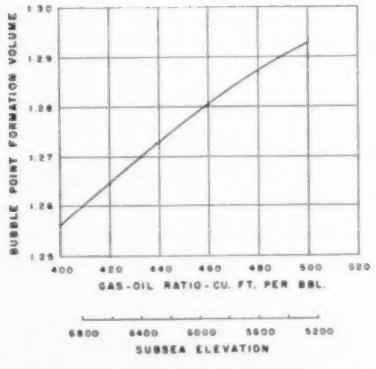

FIG. 7 — BUBBLE POINT FORMATION VOLUME FACTOR VS. SOLUTION GAS OIL RATIO.

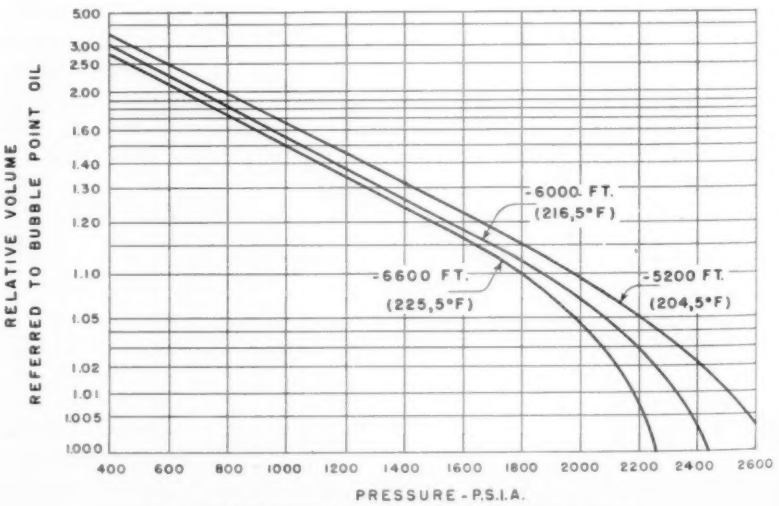

FIG. 8 — UNWEIGHTED TWO PHASE RELATIVE VOLUME DATA.

equilibrium point" can be reached at liquid saturations as high as 96%.[9] It has been the author's experience, based on the performance of gravity-drive pools in California, that where gravity segregation is occurring, gas-oil ratios will show no increase or a slight increase, even when the withdrawal data indicate the pool liquid saturation to be as low as 80%. It is conceivable that many wells, if the conditions are satisfactory, can produce to lower liquid saturations before the gas-oil ratios will increase. The attainment of continued low gas-oil ratios is an indication of the maintenance of a high liquid saturation readily explainable by gravity segregation.

It is necessary to evaluate the effect of gravity segregation on future pool performance before material balance calculations can be applied. If available, past pool performance should be used as it provides the most reliable index for future predictions. Using our type pool as an example, the following procedure illustrates one method of including the effects of gravity drive in the material balance equation.

First, the relative oil and gas volume referred to bubble point oil data, or u factor, were structurally weighted as previously illustrated in Table III. In Table V is presented a summary of the u factor as so weighted for structure. Fig. 11 presents the structurally weighted u curve as tabulated in Table V. At this point, no correction for gravity segragation has been made.

Second, material balance calculations were made for the weighted pressure averages of regularly scheduled pool pressure surveys. The results of these calculations are graphically presented in Fig. 12 on which the calculated original oil content is plotted versus the cumulative oil production at the time of the pressure determination.

The calculation of a progressively lower initial oil content, as illustrated by Fig. 12, is evidence of gravity segregation. These calculations indicate, that for the volume of reservoir oil in place, too high an expansibility factor was used. By considering the original oil band volume as a constant unit, the passage of time will find a progressively increasing percentage of oil located farther and farther down structure, where, due to the higher pressures present, the oil and gas expansibility will be lower. In the absence of gravity segregation, the reservoir oil would be distributed over the entire oil band rather than concentrated in the lower structural areas. This would result in the computation of a higher weighted u factor than that computed if the oil were influenced by gravity. All other factors being comparable, the higher the u factor the lower the initial oil content, which effect has been observed in Fig. 12.

To correct the effect of gravity segregation, the material balance equation was recalculated by holding the intial oil content constant and solving for the u factor. The modified u factor so obtained was plotted on Fig. 11 and extrapolated to lower pressure points. It is reasoned that this approach combines into one factor the effects of gravity segregation on the basic material balance, and thus provides a means of forecasting the future performance of the pool. The important requirement for such a procedure to be valid is an accurate determination of the original oil content by the pore volume method.

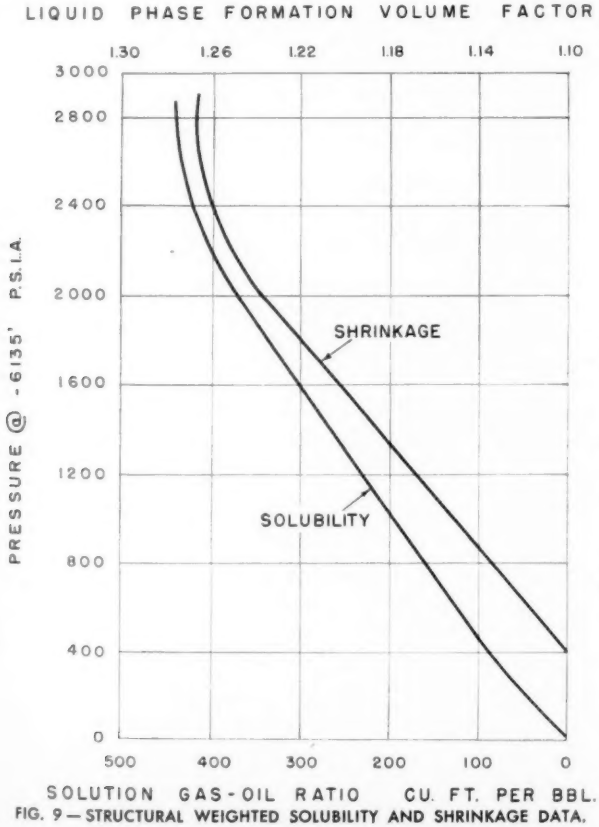

FIG. 9 — STRUCTURAL WEIGHTED SOLUBILITY AND SHRINKAGE DATA.

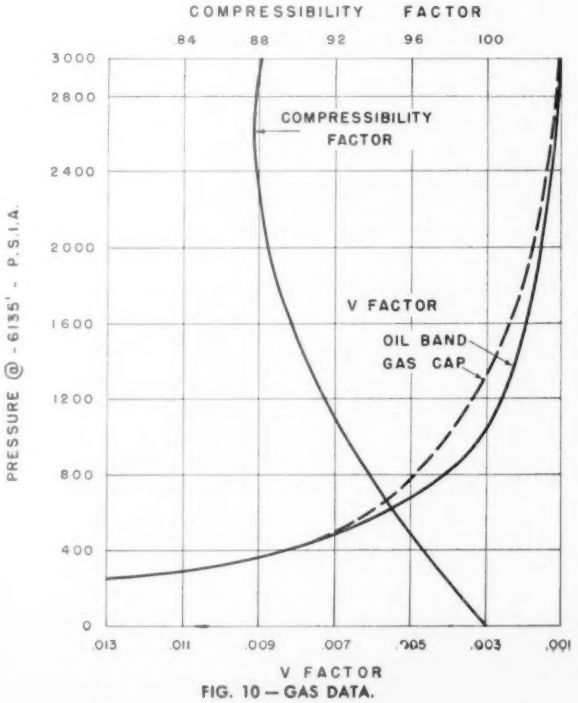

FIG. 10 — GAS DATA.

PREDICTIONS OF FUTURE RESERVOIR BEHAVIOR

Predictions of future reservoir behavior depend upon a knowledge of the saturation changes in the pool. Recent studies performed on other pools[9] have indicated that a determination of the change in the ratio of effective permeabilities of gas and oil (Kg/Ko) with changes in liquid saturation can be utilized to determine the type of reservoir drive existing and the influence of external agents upon this drive. As the produced gas-oil ratio is empirically related to the relative permeability ratio, which is related in turn to liquid and gas saturation, an analysis of gas-oil ratio performance will serve as a means of establishing the magnitude and distribution of existing saturations. The necessary requirements to apply such an analysis is a knowledge of relative permeability relationships for the pool.

As has been previously discussed, gravitational effects are responsible for the pool's average producing gas-oil ratio being considerably lower than that which would exist if the pool performance followed straight gas depletion drive. Past field performance on high relief pools indicates, that when controlled, produced gas-oil ratios will be low and will decrease rather than increase with pressure decline. For future predictions of gas-oil ratio performance, it is necessary to weight this effect of gravity segregation upon the composite pool behavior. Relative permeability relationships are controlled primarily by the liquid saturation in a reservoir and the physical nature of the rock comprising the reservoir. The laboratory procedure for the determination of relative permeability data from individual core samples satisfactorily analyzes the permeability-saturation behavior of a single core sample only. However, when such data are applied to an entire reservoir it is directly assumed that the behavior of the total reservoir is instantaneously equal to the behavior of the single core sample. In other words, it is assumed that the liquid saturation of the pool is distributed equally throughout the reservoir and maintains that distribution during the life of the pool, which assumption is incorrect if fluid migration occurs.

The existence of pressure differentials between wells, permeability variations, variations in well spacing in a pool, unequal distribution of withdrawals due to well productivities, competition, etc., and the formation of a secondary gas cap, are common conditions in most oil pools. Obviously the saturation distribution varies from well to well depending on the differences in the above variables between wells. The application of laboratory determined relative permeability data to an entire pool can easily result in an erroneous prediction of the future performance of the pool. Unfortunately the actual degree and magnitude of variation of many of the above variables cannot be correlated over an entire reservoir. The difficulty of determining the actual permeability distribution in a pool is an excellent illustration of this problem.

The use of actual pool performance data provides for a satisfactory solution of the problem. Primarily the resultant purpose of reservoir calculations is the determination of the entire pool performance. The use of weighted pool data combines into one item the differences of the variables between wells and between areas of the pool and expresses the data in terms of a single unit, namely, the pool. An analysis of past pool performance can give information as to the type and behavior drive present and the influence of external agents upon this drive.

Relative permeability relationships can be obtained from weighted pool data. The relative permeability ratios so obtained might be termed "apparent" Kg/Ko" data as they would reflect the actual behavior of the pool rather than the emperical behavior as would be calculated from laboratory determined Kg/Ko data. Changes in the withdrawal policy of the pool, such as production of excessive free gas, effect of gravity segregation on the pool, and numerous other factors, would alter the "apparent Kg/Ko" curve. The effect of these changes on the future performance of the pool could then be evaluated.

The one controlling limitation to this approach is the assumption that the pool operating factors do not materially change over the period analyzed. For example, in an efficiently

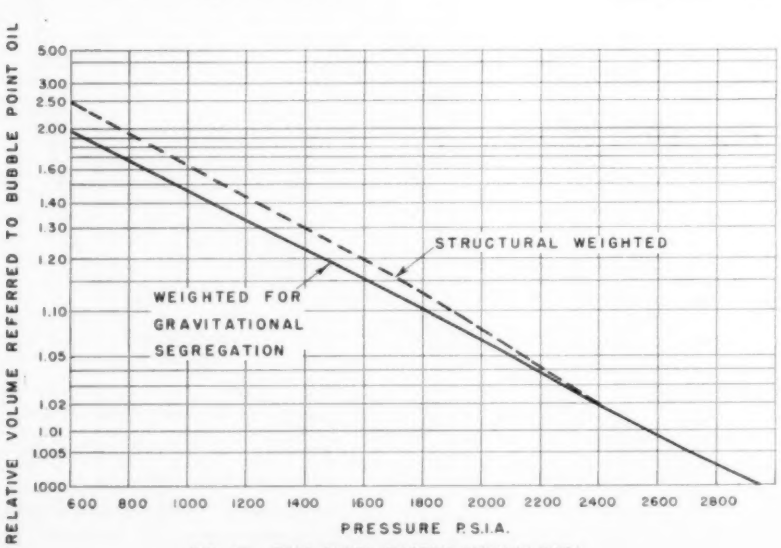

FIG. 11 — TWO PHASE RELATIVE VOLUME DATA.

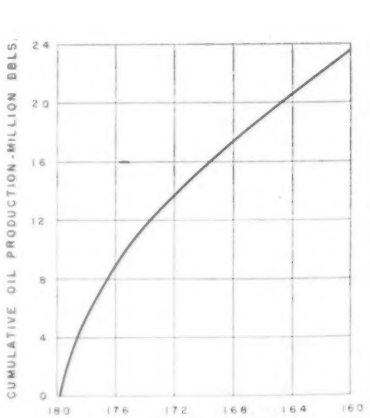

FIG. 12 — CALCULATED ORIGINAL OIL CONTENT VS. PRODUCTION.

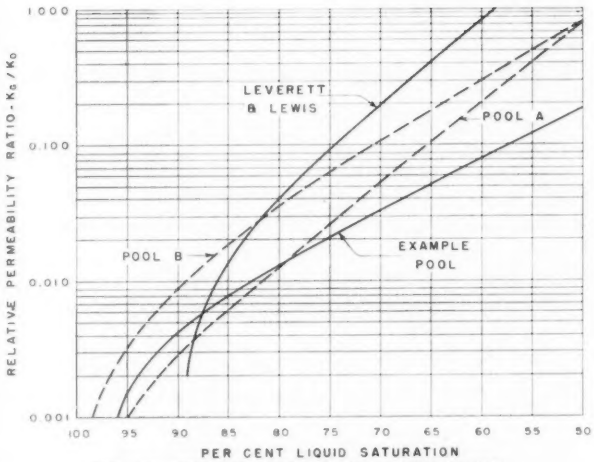

FIG. 13 — RELATIVE PERMEABILITY RELATIONSHIPS.

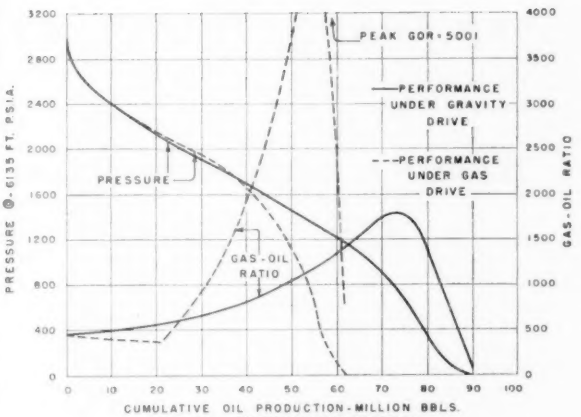

FIG. 14 — PRODUCTION HISTORY.

operated gravity drive pool, the policy of shutting in crestal wells when they go to gas must be assumed to continue in future operations. This limitation does not destroy the value of the method. Actually, the reservoir engineer can determine the future performance of a pool, if operated under past conditions, or he can determine the performance under various plans of operations by adjusting the "apparent Kg/Ko" curve to the conditions desired. This is possible as the "apparent Kg/Ko" ratio reflects instantaneous changes in pool performance caused by the influence of external agents.

In Fig. 13 are presented typical "apparent Kg/Ko" curves for several pools in California which are performing under various degrees of gravity drive. Also presented are empirical laboratory determined Kg/Ko data for unconsolidated sands.[10] The effects of gravity drive on the fields performance are readily apparent in a distinct flattening of the Kg/Ko curve.

Table VI presents a complete summary of all material balance data used in predicting future field performance of the example pool. Future pressure-production and gas-oil ratio history was calculated on a trial and error material balance approach. Fig. 14 presents the calculated pressure-production and gas-oil ratio history of the pool under gravity drive performance. Also presented on Fig. 14 is the pool pressure-production and gas-oil ratio history representing performance under gas drive which would have been calculated if laboratory determined Kg/Ko data were used. It is readily apparent that by the use of the latter data future reservoir performance would have been erroneously predicted.

SUMMARY

The procedures outlined in this paper for evaluating the effects of gravity drive upon pool performance can be summarized as follows:

1. Basic material balance data should be structurally weighted to compensate for structural differences in pressure and temperature.

2. Relative permeability relationships as computed from actual field performance data should be used in preference to laboratory determined data.

3. The oil and gas relative volume factor, or u factor, should be corrected for gravity segregation effects using actual field performance data as a guide.

The methods presented above are certainly not the complete solution to the problem of analyzing the reservoir behavior of a gravity-drive pool. Their use will provide refinement in procedure which will permit a more representative interpretation of reservoir performance.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to F. M. Cole for his advice and guidance, and to the management of the Honolulu Oil Corp. for permission to publish this paper.

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PILOT GAS INJECTION — ITS CONDUCT AND CRITERIA FOR EVALUATION

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INTRODUCTION

Injection of gas to increase oil recovery has been considered for almost all important discoveries during the past ten or fifteen years. However, the number of gas injection projects having sufficient history and data is too limited to permit valid generalities of effectiveness of gas injection. Management and engineers are faced with a difficult problem of selecting those reservoirs which are susceptible to profitable application of gas injection.

Injection of gas to maintain high pressure favors some factors affecting reservoir performance such as viscosity, surface tension, and formation volume factor of oil by keeping gas in solution and favors some operating features such as extending flowing life of wells and storing part of the produced gas for future use or sales. Injection of gas at low pressure involves lower compression ratio, or at least a single gas-gathering system, larger displacement volume in the reservoir per unit of gas handled, and permits effective utilization of the naturally existing energy and agent for oil displacement that is gas dissolved in oil. Each program is thus a compromise to meet optimum economic conditions while striving to attain maximum recovery of this important nautral resource.

The statement has often been made that pressure maintenance would greatly increase oil recovery by permitting abandonment of formation oil inflated with gas in solution rather than abandonment of the same liquid volume of tank oil, if the same terminal oil saturation could be attained. Simple calculations indicate increases in oil recovery as high as one hundred per cent on this basis for high formation volume factor oil encountered in current deep drilling. Important in this statement is "*if* the same terminal oil saturation could be attained." Implicit in this statement are the requirement of physical

TABLE I — DATA PERTAINING TO GAS INJECTION PROJECTS

Field*	Viscosity of Oil Centipoises	Formation Pressure During Injection - Psia	Shrinkage of Formation Oil From Initial Conditions to Last Point Shown‡
A†	.57 - .80	1750 - 800	11.5%
B	.5	2400 - 2100	9.0
C	1.4	300 - 50	10.0
D	1.5	400 - 40	12.0
E	.9 - 1.1	900 - 75	13.0
F	1.6	125 - 30	20.0
G	1.8	1200 - 1080	2.0
H	.52	1020 - 960	2.5
I	2.6 - 3.0	625 - 200	3.0

* Letters conform with curves shown in Fig. 1.
‡ Based on formation oil at initial conditions as 1.00.
† Pennsylvania sand field discussed in this paper.

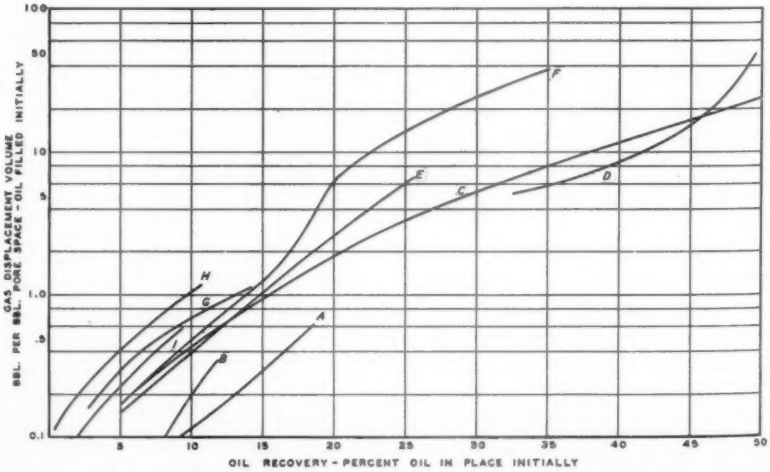

FIG. 1 — GAS INJECTION REQUIREMENTS FOR OIL RECOVERY — SANDSTONE RESERVOIRS.

Manuscript received at Petroleum Branch Office October 3, 1948. Paper presented at Branch Fall Meeting in Dallas, Texas, October 4-6, 1948.

[1] References are given at end of paper.

performance and of economics of operation of displacement of oil from heterogeneous rock. The problem is not that simple.

Except in those instances where rock, fluid properties and structural conditions combine to permit effective gravity drainage, oil must be displaced by gas or by water to be recovered. From numerous laboratory experiments the so-called relative permeability-saturation theory of oil displacement by gas has been developed. Natural production performance of many gas expansion reservoirs has shown good qualitative agreement with this theory. However, it has yet to be demonstrated that the primary production performance can be extrapolated quantitatively to accurately predict reservoir performance with gas injection.

Relation between gas displacement volumes and percentage oil recovery for nine gas injection projects in sand reservoirs is plotted in Fig. 1 and important properties of crude oil and formation pressures during injection are presented in Table I. Since oil displaced by injected gas cannot be segregated from the total oil produced, gas expansion in the reservoir has been added to volume of gas injected. Regional gravity segregation is believed to be negligible in all cases except "F", but even in this field gas injection has been dispersed in the down-structure area to drive the oil into producing wells.

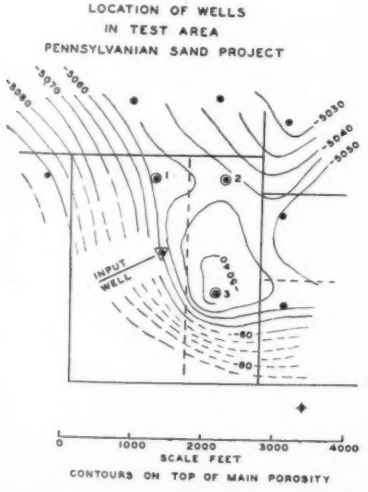

FIG. 2 — LOCATION OF WELLS IN TEST AREA,

With reservoir pressures ranging from 30 to 2200 psia for these projects, it is striking that total gas volume and oil viscosity appear to be the principal factors causing deviation from the mean and that pressure per se does not appear to be important. A nearly linear relation exists between viscosity and gas volume requirements except for Field "H", for the same oil recovery at least in the lower ranges. In the higher ranges variation in sand properties probably become more important although no definitive criteria are obvious. Injection of gas at high pressure requires considerably more gas handling to inject the same formation volume of gas than does injection at low pressure.

Even though these case histories of gas injection which include all the vicissitudes of field operation, well completion, gas channeling, etc., show good general agreement, it does not follow that circulation of a particular volume of gas measured under reservoir conditions will guarantee that indicated oil recovery will necessarily be attained. Since it has been demonstrated that oil is recovered primarily due to actual displacement by gas, it is necessary that the introduction of gas into the reservoir be controlled to insure that it will flow through the maximum possible part of the oil-filled pore space. Herein lies an important distinction between the displacing ability of gas dissolved in oil in a reservoir and gas injected through wells. Expansion of gas released from solution in oil provides energy and a displacing agent in each pore in which oil exists, while injected gas of necessity, in following the line of least resistance, is capable of displacing oil from only a part of a reservoir before gas circulation ratio to oil recovery becomes economically prohibitive.

This part of the reservoir which can be effectively swept by injected gas — a function of permeability profile—can be partly determined for particular reservoirs by relatively short-term pilot gas injection tests. Case histories of pilot gas injection in one sand reservoir and two lime reservoirs are presented to show the procedures used, results obtained, and methods of interpretation.

Pilot gas injection tests also provide direct measure of well intake capacities which aid in designing compressor pressure requirements and in determining number of input wells required. The primary answer of economic importance, however, is reaction of the reservoir to injected gas.

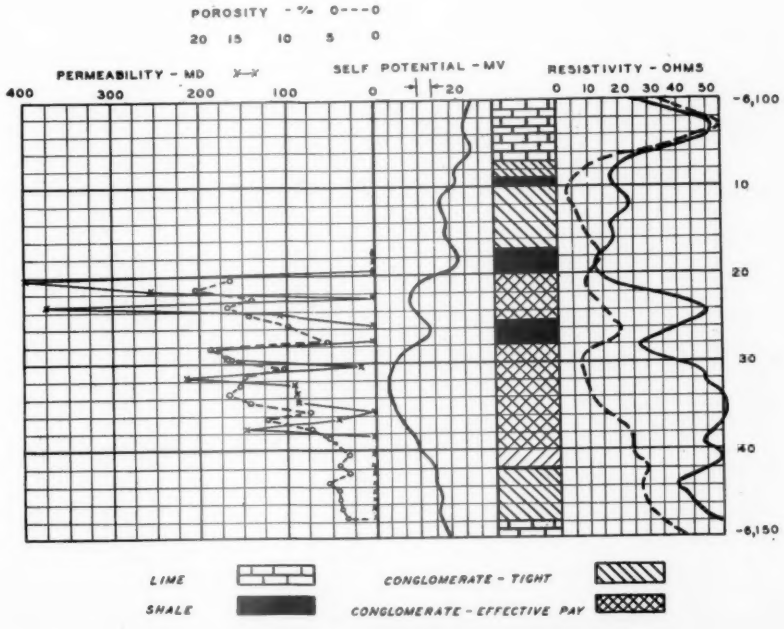

FIG. 3 — TYPICAL LOG, PENNSYLVANIAN SAND PROJECT.

LOWER PENNSYLVANIAN SAND RESERVOIR

A pilot injection experiment was conducted in the Second Conglomerate Reservoir, Lower Pennsylvanian sand, in a field in Texas. Location of input well and offset producing test wells are shown on the map in Fig. 2 on which contours on top of main porosity are super-imposed. Although this test area is a separate nose of the main structure, all wells involved are within fifteen feet of the same elevation, so gravity segregation effects should be minor. Typical characteristics of this reservoir are outlined on the composite log in Fig. 3. Unfortunately, no core analyses were available for any of the test wells, but general correspondence with the log shown is believed to exist.

Individual production facilities including separators, gas meters, and oil meters were installed for each of the test wells so that continuous daily measurement of the produced fluids would provide a complete and accurate record of detailed reservoir performance. Fig. 4 shows performance of well No. 1, the north offset to the input well throughout the test period. Gas-oil ratios rose distinctly within three months after gas injection started and increased to a maximum of about 3500 cubic feet per barrel just before gas injection was curtailed. Gas-oil ratios then fell off rapidly, and within six months after gas injection was completely stopped they had declined to nearly the same value existing before gas injection started. The cross-hatched area on the curve represents difference between actual produced gas-oil ratio and that which probably would have existed without gas injection. Similar individual well performance of other wells more remote from the input well showed no significant variation in gas-oil ratio during this period.

Performance of well No. 2, the northeast diagonal offset to the input well is illustrated in Fig. 5. Gas-oil ratio performance similar to that of well No. 1 existed, though the peak gas-oil ratio was just slightly in excess of 2000 cubic feet per barrel. Here, too, the gas-oil ratio declined to its original value following cessation of gas injection.

Performance of well No. 3, the east offset to the input well, is illustrated in Fig. 6. Gas-oil ratios increased significantly about six months after gas injection started and also declined following cessation of gas injection. Gas-oil ratio without gas injection outlined on this curve is probably conservative with reference to excess gas production, since ratios of other wells in the area remained low throughout most of 1945, but at least it indicates minimum channeling of injected gas.

Reservoir pressure when gas injection started was 2000 to 2050 psi—just 50 to 100 psi below the original saturation pressure of oil in the reservoir. Thus gas injection began before significant free gas saturation had developed in the reservoir—a condition considered essential by many engineers. Maximum gas channeling was experienced at well No. 1 which produced double allotment due to transfer of allowable production from the input well. More concentrated withdrawal may easily have directed injected gas toward this well to create this gas channel of higher capacity.

Gas injection was discontinued in September, 1945, and the input well remained shut in until January 22, 1946, when it was returned to production. Performance of this well is illustrated in Fig. 7. It should be noted that oil was obtained the first day of production and and that within two months the gas-oil ratio and oil production had reached a status not greatly different than other wells in that area of the field, even though cumulative back-flow gas production from the input well was only 10 per cent of the volume of gas injected into the reservoir.

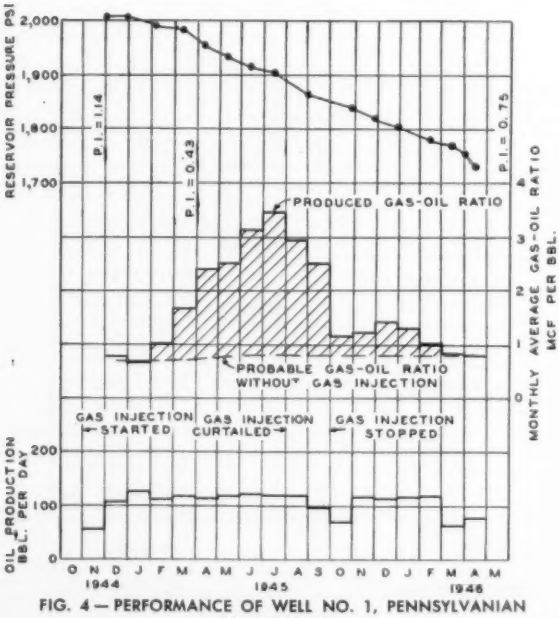

FIG. 4 — PERFORMANCE OF WELL NO. 1, PENNSYLVANIAN SAND PROJECT.

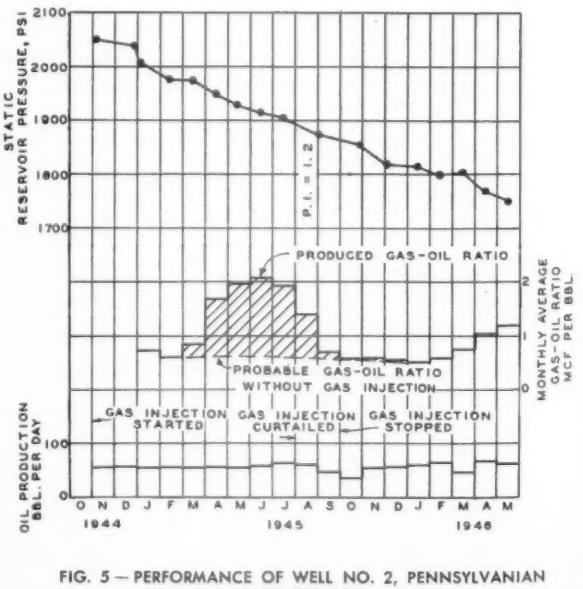

FIG. 5 — PERFORMANCE OF WELL NO. 2, PENNSYLVANIAN SAND PROJECT.

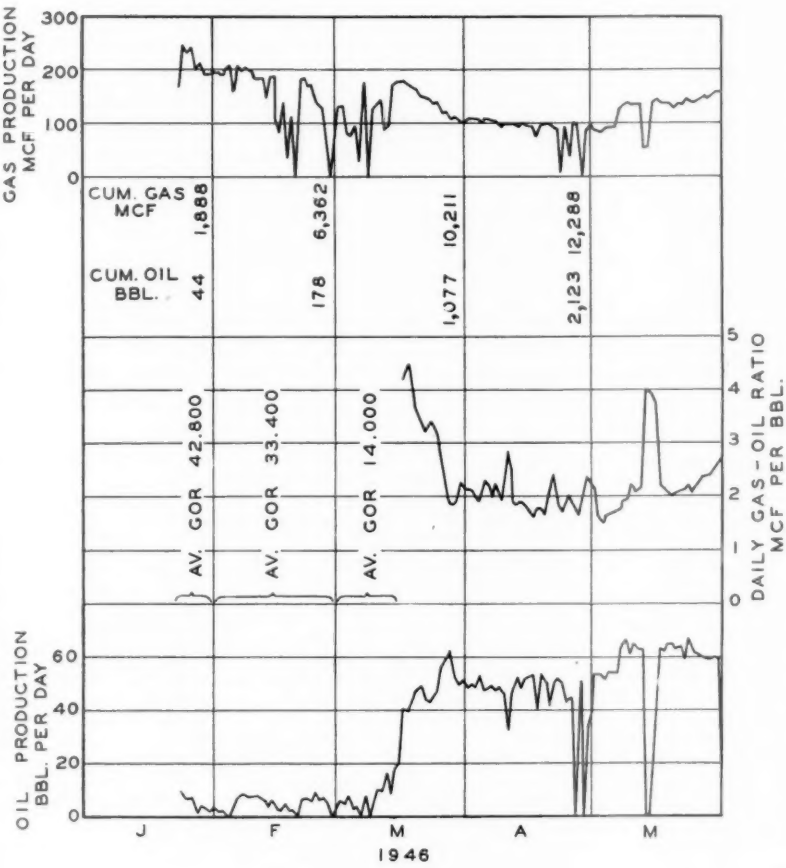

FIG. 7 — PERFORMANCE OF INPUT WELL RETURNED TO PRODUCTION.

Detail of gas injection rate and of excess gas production from these three test wells is outlined in Fig. 8. Within nine months of beginning gas injection, rate of excess gas production of three offset wells was nearly equal to the rate of gas injection. Gas injection was primarily gas circulation without significantly effecting further oil recovery.

Cumulative gas injection and cumulative excess gas production from these three offset wells are shown in the lower part of this chart. Of the 102 M³cf gas injected, maximum amount "stored" in the reservoir was about 44 M³cf occupying some 50,000 barrels in reservoir environment. Reservoir pore space in the area is about 26,000 barrels per acre or 4,200,000 barrels for the assumed 160-acre drainage area of the four wells involved. Thus these gas channels occupied only 1.2 per cent of the pore space involved when rate of excess gas production was essentially equal to rate of gas injection. Considering "stored" gas to be confined within linear bounds of the wells raises the fraction of pore space occupied to about four per cent, but it is unlikely that such condition existed entirely and at least all production did not come from these confines.

Reaction of oil productivity to injected gas is illustrated by PI history of well No. 1. Productivity index, which

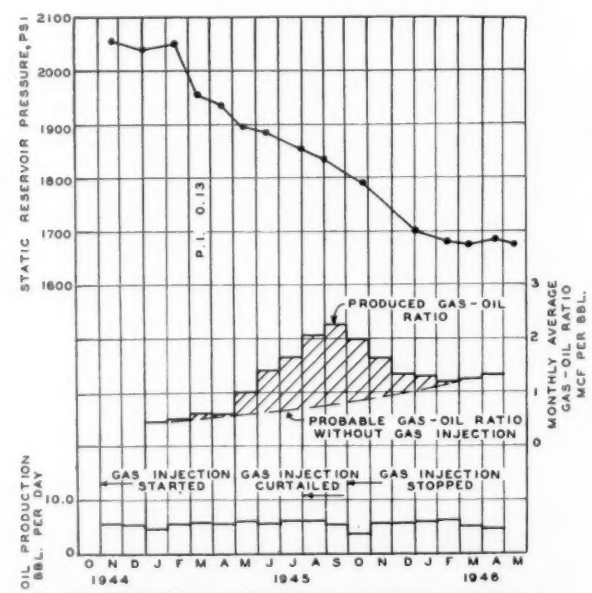

FIG. 6 — PERFORMANCE OF WELL NO. 3, PENNSYLVANIAN SAND PROJECT.

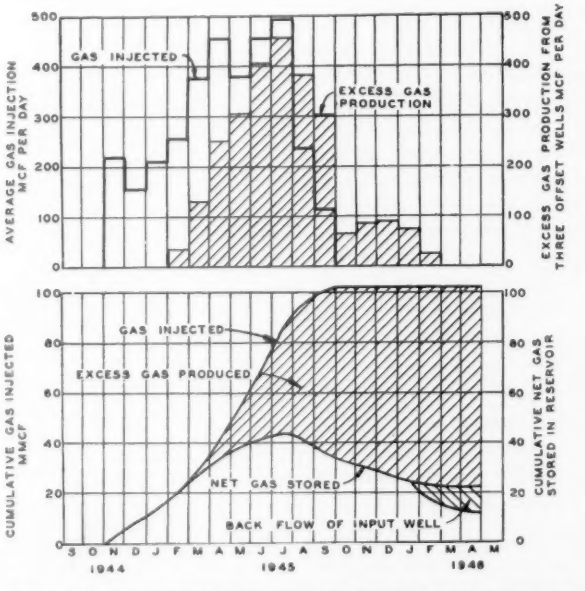

FIG. 8 — GAS INJECTION RATE AND EXCESS GAS PRODUCTION IN 3 TEST WELLS, PENNSYLVANIAN SAND PROJECT.

was 1.14 barrels oil per day per psi prior to gas injection, declined to 0.43 before excess gas production reached its peak. It increased considerably to 0.75 after gas injection was stopped and gas-oil ratio had returned to normal. Both gas-oil ratio and oil productivity performanee indicate these gas channels became at least partly resaturated with oil when gas injection was stopped. Much of this oil probably came from adjoining by-passed portions of the reservoir, but part might have come from outside the test area. If these conclusions are generally applied to this reservoir, they mean that no lasting effect was obtained from the gas injection. To maintain this "stored" gas volume at existing pressure would require circulation of about 450 Mcf per day till flow of oil from by-passed parts of the reservoir declined to uneconomic rate. At 2c per Mcf compression cost this would amount to $3,300 per year plus the pro rata share of gas gathering and gas injection system expense to maintain 50,000 barrels of pore space (containing about 36,000 barrels of tank oil initially) swept free of oil. Not all of this oil could be considered increase in ultimate recovery since very little free gas existed at time of gas injection began and oil recovery by natural means would be expected to be highest in these most permeable channels. Such cost calculation is probably very inaccurate, but at least it shows magnitude involved.

Gas injection was continued in this field at the top of the main structure. Over-all pool performance—obtained by totaling individual well production of oil and gas measured by separate meters—is summarized in Fig. 9. Of importance is gas-oil ratio performance during March, April and May, 1946, covering a period when gas injection was stopped. Normal interpretation of this composite data is that gas-oil ratios were not sensitive to gas injection and thus that gas injection was successful —contrary to the inferences of pilot gas injection.

Analysis of detailed performance of individual wells, however, indicates interpretation of composite data to be erroneous. Fig. 10 shows performance of one 40-acre diagonal offset to the injection well. Immediate reaction to stopping gas injection on March 23, 1946 and resuming it on May 20, 1946 was noted. So striking, in fact, was this reaction that gas-oil ratios of this well alone indicated time almost to the day of stopping and starting the compressor. Decline in gas-oil ratio during this period for this and four other wells multiplied by their respective oil rates equals about 40 per cent of the gas injection rate just prior to the period—and none of these wells had attained a stabilized minimum gas-oil ratio. Thus much of the injected gas was being cycled to five producing wells. Small effect on pool average gas-oil ratio was apparent because edge wells remote from the injection area had reached a stage of depletion where gas-oil ratios were increasing rapidly. Reduction in pool gas-oil ratio at beginning of 1947 was attained by shutting in high gas-oil ratio wells when the field was unitized.

Performance of this reservoir has illustrated the importance of detailed analysis performance of individual wells. It has indicated ease of making false conclusions even though over-all pool performance data are accurate.

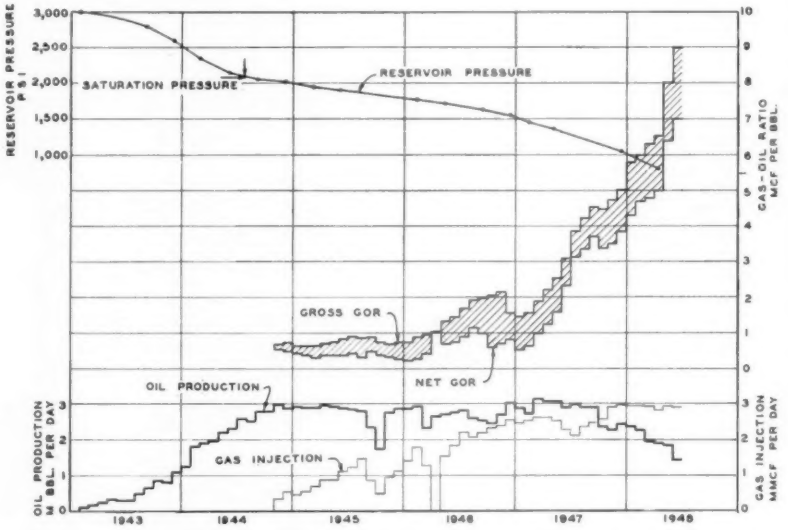

FIG. 9 — POOL PERFORMANCE, PENNSYLVANIAN SAND PROJECT.

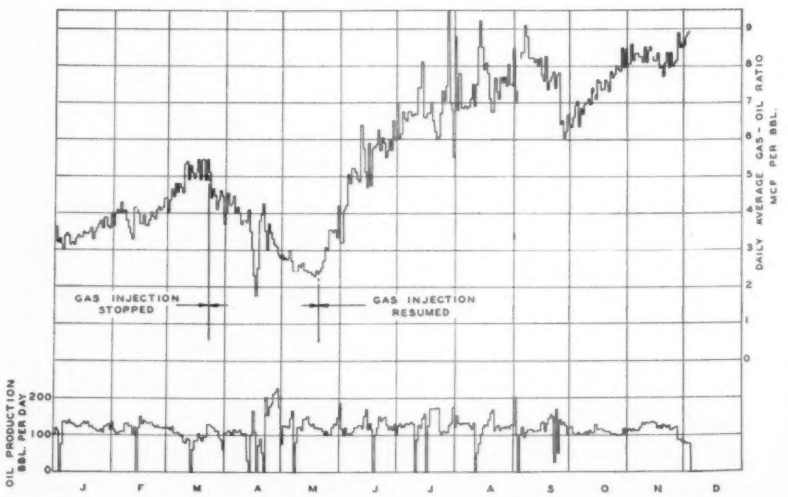

FIG. 10 — WELL PERFORMANCE OF 40-ACRE DIAGONAL OFFSET TO INPUT WELL, PENNSYLVANIAN SAND PROJECT.

SAN ANDRES LIMESTONE RESERVOIR

A series of pilot gas injection tests was conducted in a San Andres lime reservoir to determine intake capacities of wells and finally to determine effect of gas injection on gas-oil ratios of producing wells near the input well. Fig. 11 shows location of wells grouped by tank batteries for the final long-term injection test. All wells were set on fixed positive chokes of such size to permit production of allowable each month with a flowing schedule of six hours each day, and no chokes were changed during the pilot injection program. Total gas and oil production of wells in each tank battery were measured continuously for one month prior to gas injection, through the five-month injection period, and for at least one month following gas injection.

Fifty million cubic feet of gas were injected which at formation conditions represent about 88,000 barrels or less than 30 per cent of the volume of oil and gas produced from the test area during injection and less than 0.25 per cent of reservoir pore volume in the test area. The input well back-flowed about 12 per cent of the injected gas before any oil was produced; about 31 per cent when its gas-oil ratio declined to 4000 cubic feet per barrel, and about 45 per cent when it had declined to 2000 cubic feet per barrel.

Possible gas-oil ratios without gas injection are outlined for tank batteries 1, 3, 5, 6 and 7, based on reduced trends in gas-oil ratio when gas injection was stopped. These hatched areas indicate that as much as 16 per cent of the injected gas may have been produced. However, these indicated gas-oil ratios without gas injection should be considered just as reasonable possibilities since none of the changes in gas-oil ratio trend exceeded 200 cubic feet per barrel, and particularly since there is no assurance that wells in each tank battery contributed uniformly to oil production even though chokes were fixed.

The only valid conclusion that can be made regarding this test is that daily gas injection rate and total gas injection volume were too small to effect changes in reservoir performance that were significant enough to permit accurate interpretation.

GRAYBURG LIME GAS INJECTION EXPERIMENT

The paper *Importance of Injected Gas as a Driving Medium in Limestone Reservoirs*, by L. E. Elkins[1], reports an experimental gas injection project in a West Texas Grayburg lime field. Map of test area is presented in Fig. 15, showing location of input and producing wells. First and second row offsets to the input well on 40-acre spacing were included in the test.

Performance of this group of wells is outlined on the chart in Fig. 16, showing average reservoir pressure, gas injection rate, oil production rate, average gas-oil ratio and reservoir fluid withdrawal. Eleven months of gas injection totaled 52 M²cf before significant rise in gas-oil ratio. This increase occurred simultaneously with a large increase in oil production rate and with a large increase in gas injection rate, so effects of gas injection cannot be segregated. Rate of gas production in excess of that calculated from a possible linear trend of gas-oil ratio from August, 1945 to January, 1945 is almost always in excess of gas injection rate. Much of this performance must have been due to oil production from permeable channels at a rate faster than oil flowed from the less permeable parts of the reservoir with then existing pressure differences. Approximate increase in gas-oil ratio during gas injection and approximate reduction in gas-oil ratio during six months after gas injection was stopped are shown for each well on the map in Fig. 15.

Formation volume of total 167 M²cf injected was about 300,000 barrels, or about 1.8 per cent of the estimated

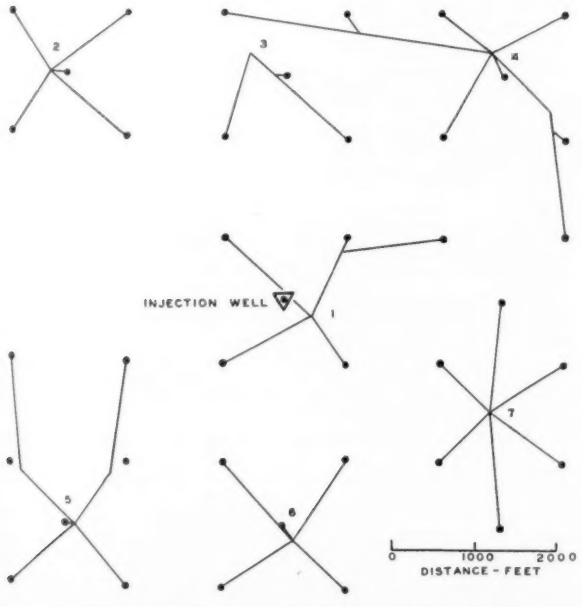

FIG. 11 — LOCATION OF TEST TANK BATTERIES, SAN ANDRES LIME PROJECT.

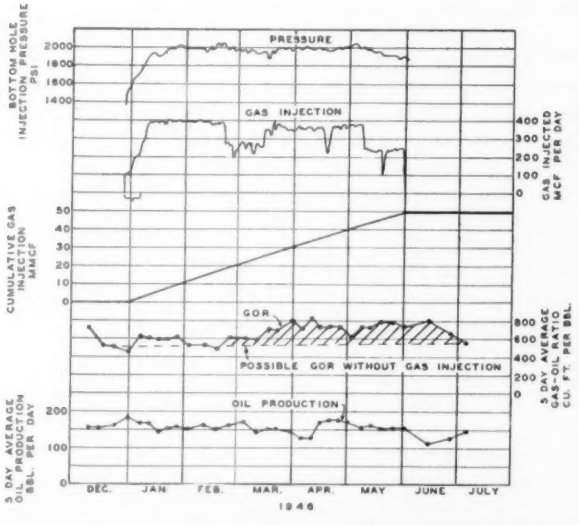

FIG. 12 — GAS INJECTION DATA AND PERFORMANCE OF BATTERY NO. 1, SAN ANDRES LIME PROJECT.

16,500,000 barrels pore space in the test area. Whatever injected gas contributed to observed gas-oil ratio performance thus occurred at a relatively low saturation of injected gas.

Reduction in gas-oil ratio from 3400 cubic feet per barrel in July, 1944 to 1700 cubic feet per barrel in January, 1945, during reduction in average oil saturation, was probably due to equalization of oil saturation between flow channels and more massive rock. Fluid flow from massive rock into permeable channels during this period was probably at a gas-oil ratio at least as low as 1700 cubic feet per barrel. If the reasonable assumption be made that a volume of gas and oil equal to production of about 1,000,000 barrels entered the permeable channels, this would include about 237,000 barrels of tank oil at a gas-oil ratio of 1700 cubic feet per barrel. Production of 172,000 barrels leaves a net increase of 65,000 barrels of tank oil in permeable channels, 0.4 per cent of total pore space, to reduce average produced gas-oil ratio from 3400 to 1700 cubic feet per barrel. Flow channels thus appear to be a relatively small fraction of the total pore space.

Rapid drop in pressure following increase in production rate in September, 1943 provides another approach to calculating effective fraction of reservoir voids in which action of injected gas may be presumed to be concentrated. Reservoir pressure and fluid withdrawal rates are plotted versus cumulative net fluid withdrawal in Fig. 17. During September and October, 1943, reservoir pressure dropped 150 psi with a net fluid withdrawal of 90,000 barrels. This amounts to only 600 barrels per psi while the calculated expansibility of reservoir fluids in the test area is of the order of 5700 barrels per psi. Apparent reservoir fluid expansibility was only ten per cent of the theoretical value assuming pressure equilibrium in all parts of the reservoir. At only 60 psi lower pressure in March, April and May, 1944, production of 2500 barrels per day was maintained with no drop in pressure which might represent rate of flow into the permeable channels. The 600-barrel production per psi includes some of this flow, but it is in any event the maximum indicated expansibility. The fraction of total reservoir pore space indicated to comprise these channels is roughly ten per cent.

The only other plausible explanation of reservoir performance considered in these two analyses is lack of equalization of pressure and oil saturation between that portion of the reservoir near the wells and those portions more remote. Effects of drainage area and of fluid flow into permeable channels tend to offset each other in the pressure-production analysis, but to what degree cannot be determined.

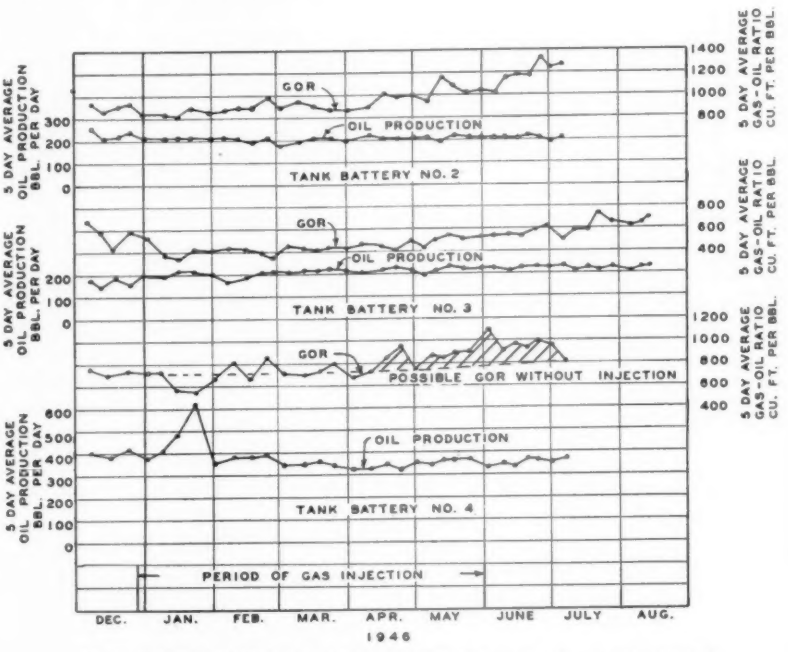
5 DAY AVERAGE OIL PRODUCTION BBL. PER DAY
5 DAY AVERAGE GAS-OIL RATIO CU. FT. PER BBL.
GOR
OIL PRODUCTION
TANK BATTERY NO. 2
TANK BATTERY NO. 3
POSSIBLE GOR WITHOUT INJECTION
TANK BATTERY NO. 4
PERIOD OF GAS INJECTION
DEC. JAN. FEB. MAR. APR. MAY JUNE JULY AUG.
1946

FIG. 13 — PERFORMANCE OF TANK BATTERIES NO. 2, 3 AND 4, SAN ANDRES DOLOMITE PROJECT.

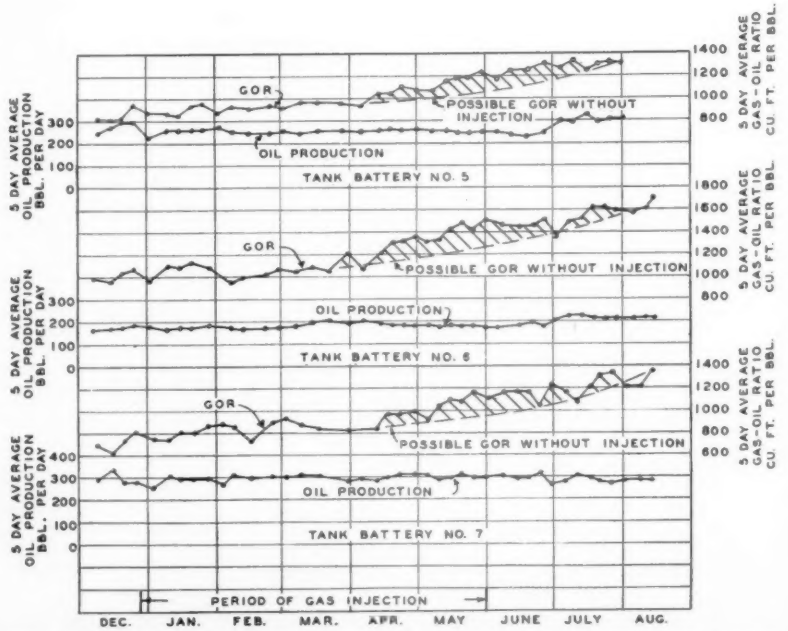
5 DAY AVERAGE OIL PRODUCTION BBL. PER DAY
5 DAY AVERAGE GAS-OIL RATIO CU. FT. PER BBL.
GOR
POSSIBLE GOR WITHOUT INJECTION
OIL PRODUCTION
TANK BATTERY NO. 5
TANK BATTERY NO. 6
TANK BATTERY NO. 7
PERIOD OF GAS INJECTION
DEC. JAN. FEB. MAR. APR. MAY JUNE JULY AUG.

FIG. 14 — PERFORMANCE OF TANK BATTERIES NO. 5, 6 AND 7, SAN ANDRES LIME PROJECT.

SUMMARY

Performance of eight gas injection projects in sand reservoirs has demonstrated that recovery of oil by injection of gas is primarily due to displacement. Thus the fraction of the reservoir through which injected gas will flow—controlled by effective permeability profile—is of utmost importance. Three case histories of pilot gas injection have been presented showing results obtained and methods of interpretation. Continued gas injection in one field confirmed the implications of pilot gas injection.

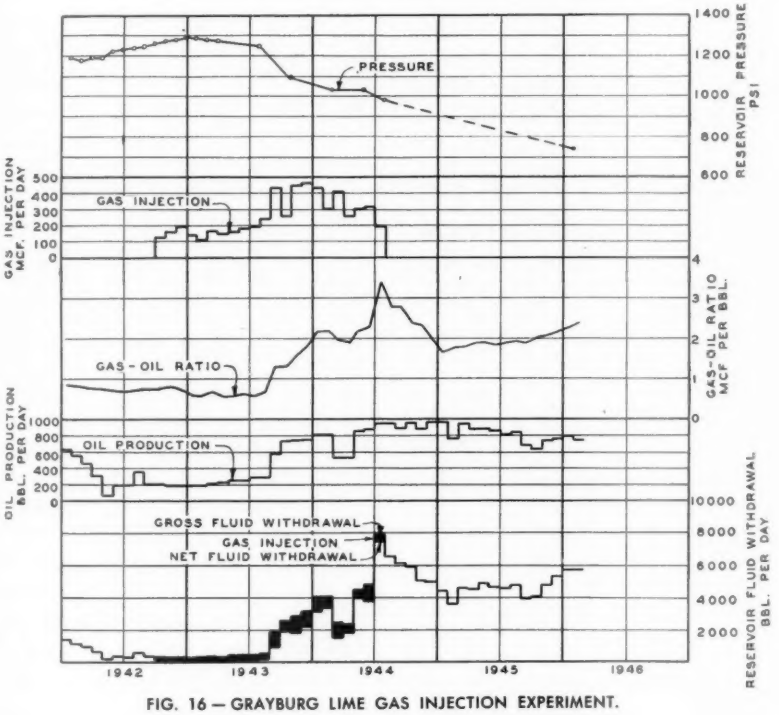

FIG. 16 — GRAYBURG LIME GAS INJECTION EXPERIMENT.

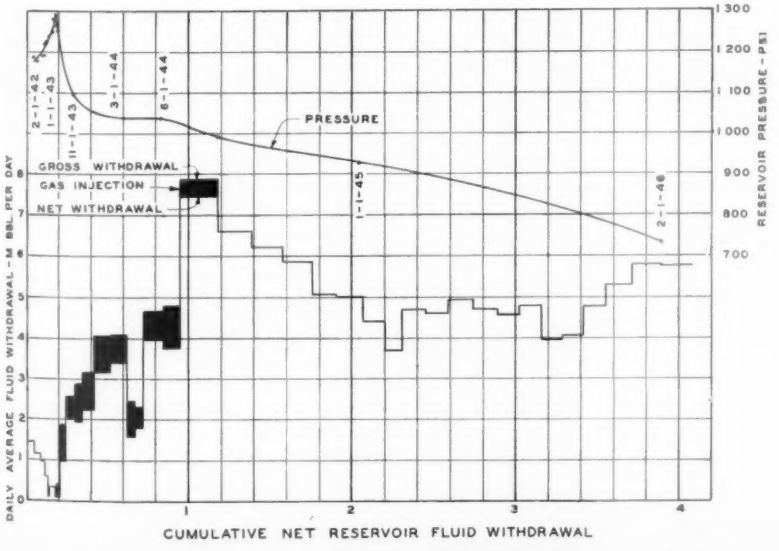

FIG. 17 — RESERVOIR PRESSURE AND FLUID WITHDRAWAL RATES VS. CUMULATIVE NET FLUID WITHDRAWAL, GRAYBURG LIME PROJECT.

So-called "conformance factors"[2] or reservoir sweep efficiencies were found to be quite low—of the order of 10 to 20 per cent—in the two cases having gas injection at sufficient rate and volume to permit reliable interpretation. It appears that injection of sufficient gas to maintain formation pressure in these two instances would be inadvisable. Reduction of pressure to permit expansion of gas in those parts of the reservoir unaffected by injected gas would be necessary to effect recovery of oil therefrom.

RECOMMENDATIONS FOR FUTURE PILOT INJECTION

From these pilot injection projects and others it appears to the authors that reliable conclusions depend upon:

(1) Injection of gas at sufficient rate and for a long enough period to cause significant changes in produced gas-oil ratio. Daily injection should at least replace volume of fluids produced by first-row offset wells.

(2) Adequate measurement of performance of individual wells to provide accurate data. Continuous measurement is desirable.

(3) Adequate test period before and after gas injection to determine normal trend in gas-oil ratio without gas injection.

(4) Conduction of pilot gas injection

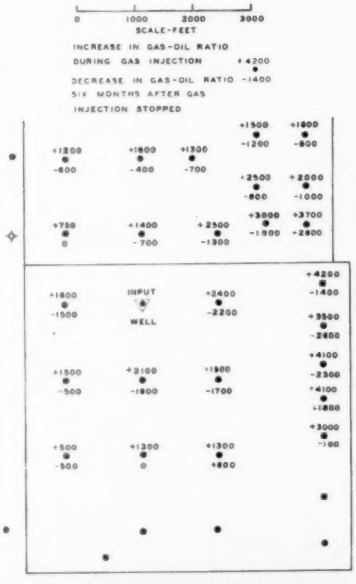
SCALE-FEET
INCREASE IN GAS-OIL RATIO DURING GAS INJECTION
DECREASE IN GAS-OIL RATIO SIX MONTHS AFTER GAS INJECTION STOPPED
INPUT WELL

FIG. 15 — WEST TEXAS, GRAYBURG LIME GAS INJECTION EXPERIMENT.

early in pool life to reduce error involved in estimate of gas-oil ratio without gas injection.

ACKNOWLEDGMENT

The authors wish to express their thanks for these data to the companies which conducted these field tests and to Sohio Pet. Co. for permission to publish this paper.

REFERENCES

1. "Importance of Injected Gas as a Driving Medium in Limestone Reservoirs", Lloyd E. Elkins, *A.P.I. Drill. and Prod. Practice*, 1946, pp. 160-174.
2. "Evaluation of Pressure Maintenance by Internal Gas Injection in Volumetrically Controlled Reservoirs", E. Charles Patton, Jr., AIME *Trans.*, 1947, pp. 112-155.

DISCUSSION

By Ralph U. Fitting, Jr., Fitting, Fitting & Jones, Midland, Texas.

This paper is one for which there has been great need, as it presents additional evidence on a very important current problem. Are those limestone reservoirs which are characterized by two systems of porosity susceptible to the increase of oil recovery by gas injection? These two porosity systems are the intergranular type and the hetergeneous type; the latter being important because it tends to short-circuit fluid flow.

No one should approach this question with the view that economics is the governing control as to feasibility; the physics of fluid flow in these porosity types is yet unsolved. Everyone should be fully aware that, as the authors state, the experience, history, and interpretation is too limited to permit valid generalities as to the effectiveness of gas injection in reservoirs of this type.

In Texas, oil operators are being confronted with the problem of the injection of gas into the oil reservoirs for the purpose of saving that gas from destruction. Yet it must be recognized that in some fields such a procedure actually results in the cycling of gas selectively through portions of the reservoir and when this occurs, no gas storage is feasible. Creation of such gas-filled layers in the reservoir allows excessive loss of solution gas, which otherwise would do effective work; such gas moves to the well bore in the zone of high gas saturation.

Furthermore, the cycling of dry gas through the reservoir may cause the reservoir oil to assume the very characteristics which pressure maintenance by gas injection is presumed to avoid. These characteristics are that the reservoir oil becomes more viscous rather than less viscous, this being due to the loss of the higher gaseous fractions in solution in that liquid into the dry gas in much the same manner as the reverse process occurs in the gasoline plant.

Certainly, the maintenance of pressure tends to nullify the pressure gradient causing vertical migration of oil from the dense to the permeable rock. In those reservoirs where the oil volume contained in the dense rock is large as compared with that contained in the permeable rock, oil recovery could be materially affected adversely by gas introduction into the portions of the reservoir with high permeability. These adits, permitting communication of the recesses of the reservoir with the well, must be continued with high liquid saturation for as long as it is possible to do so.

Another of the problems which must be solved in this matter of gas injection is to determine at what time gas should be introduced into a limestone oil field, if ever; that is, before or after primary pressure has been depleted. This paper would evidence that total gas volume and oil viscosity, even in sandstone fields, appear to be the principal factors causing variations in the quantity of oil recovered in gas injection and that the remaining pressure of the reservoir at the time of gas injection does not appear to be important. The paper further indicates that there is no axiom that circulation through an oil reservoir of any particular volume of gas will guarantee additional oil recovery.

It is important that those people who dictate the policy practices in the oil industry understand the mounting evidence as to the experimental nature of gas injection projects in limestone reservoirs, particularly those in West Texas. ★ ★ ★

EXPERIMENTS ON THE CAPILLARY PROPERTIES OF POROUS SOLIDS

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MAURICE LEWIS, JR., JUNIOR MEMBER AIME, and **R. C. NEWMAN,** STUDENT ASSOCIATE AIME

ABSTRACT

A report is made of experimental work performed on the capillary retention of water within porous solid systems, the displacement being accomplished with air and various organic liquids. A portion of the experiments were designed to measure the lowering of vapor pressure of water within a porous solid with subsequent conversion of such vapor pressure data to capillary pressure values. The form of the capillary pressure curve at high capillary pressures has been elucidated from this data. Certain theoretical approaches are presented to indicate the correlation between work done by previous investigators. The present work is correlated also with theory. Surface area values are calculated for the various core systems studied.

INTRODUCTION

Leverett[1] in 1941 presented a paper which gave the essential concepts of capillary behavior in porous solids. His presentation included both theoretical and experimental aspects of the problem. He defined the term "capillary pressure" and applied it to an ideal porous system. His work included the definition of a dimensionless quantity which was a function of fluid saturation and which could be correlated with porosity and permeability for clean, unconsolidated sands. His experimental work was performed by the drainage of water from packed columns of unconsolidated sands.

Subsequently, other authors have presented experimental techniques which permit the determination of capillary pressure data on small core samples. Data have been presented on porous systems other than unconsolidated sand and with the use of liquids other than water. Notable among these are the works of Hassler, Brunner and Deahl,[2] Bruce and Welge,[3] Amyx and Yuster,[4] and Purcell.[5] Others[6,7] have indicated the applicability of such data to field problems without regard to the theoretical aspects of the capillary pressure saturation function. Within the recent published literature there have also been reported studies of the correlations between capillary pressure data and other fundamental properties of porous solids.[8,9,9]

It was the intent of the present reported work to investigate the behavior noted by water and various other liquids within porous systems in an attempt to amplify existing correlations between capillary properties, surface properties, and other fundamental characteristics of porous systems. The experimental work described here was performed as two different investigations but due to its nature it is reported as separate phases of the same general topic.

CAPILLARY PRESSURE AND VAPOR PRESSURE LOWERING

It has long been recognized that the vapor pressure above the curved surface of a liquid is a function of the curvature of the liquid surface.[10] The capillary pressure is also a function of the curvature of the liquid surface. Both capillary pressure values and vapor pressure lowering are, therefore, functions of the liquid saturation of a porous solid. A quantitative relationship between the vapor pressure lowering and the capillary pressure can be simply developed by considering a porous solid system containing water in equilibrium with its vapor.

The capillary pressure at any height within the system is defined as

$$P_c = P_v - P_l \quad \text{- - - - - - - - (1)}$$

where P_v is the pressure in the vapor phase and P_l is the pressure in the liquid phase. Consider that both the water and its vapor are continuous phases within the system and that at any point the two phases are in equilibrium.

The gradients in the liquid and vapor columns within the porous system are:

$$dP_l = \rho_l g dh$$

$$dP_v = \rho_v g dh$$

By integrating these gradients from the point where $h = 0$ to the height h, values of P_l and P_v at the point h are found. Let the point where $h = 0$ be that where $P_c = 0$. At this point also P_v is equal to P_{vo}, the equilibrium vapor pressure of the liquid above a flat surface.

From the first of these integrations since ρ_l is independent of height:

$$P_l = \rho_l g h + P_{vo}$$

From the second, by substituting $\rho_v = \frac{P_v M}{RT}$, where M is the molecular weight:

$$\ln \frac{P_v}{P_{vo}} = \frac{M}{RT} gh$$

By combining the two last equations to eliminate h, one obtains:

$$P_l = \frac{RT}{M} \rho_l \ln \frac{P_v}{P_{vo}} - P_{vo}$$

Substituting values for P_v and P_l in equation (1) gives

$$P_c = \frac{\rho_v RT}{M} - \frac{RT}{M} \rho_l \ln \frac{P_v}{P_{vo}} - P_{vo}$$

or $$P_c = \frac{RT\rho_v}{M}\left[1 - \frac{\rho_l}{\rho_v} \ln \frac{P_v}{P_{vo}}\right] - P_{vo}$$

which is approximately

$$P_c = \frac{RT}{M} \rho_l \ln \frac{P_{vo}}{P_v} \quad \text{- - - - - - (2)}$$

This equation relates the vapor pressure above a curved surface with the capillary pressure across the curved surface in terms of measurable quantities. The equivalent of this equation is given by Freundlich.[10]

Manuscript received at office of the Branch January 24, 1949. Presented at AIME Annual Meeting, San Francisco, Calif., February 13-17, 1949.

[1] References are given at end of paper.

There is much data in the literature on vapor pressures within porous solids at partial liquid saturations. Such data are often procured for adsorption measurements. To illustrate the conversion of data by equation (2), data on the adsorption of water vapor by silica gel were taken from the literature.[11] The data, given as pressure of adsorption versus saturation, were converted to values of P_c by equation (2). The vapor pressure curves and corresponding capillary pressure curves are shown in Fig. 1. The hysteresis loop is similar to that shown by Leverett[1] on his capillary pressure curves for unconsolidated sands.

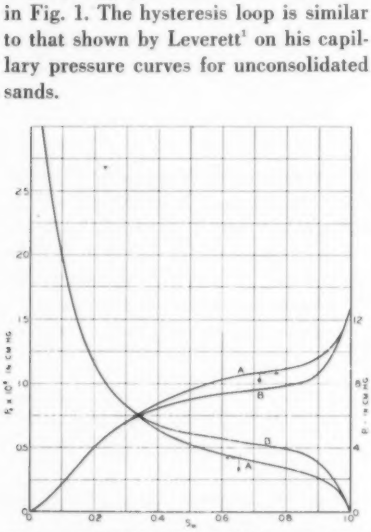

FIG. 1 — CONVERSION OF VAPOR PRESSURE DATA TO CAPILLARY PRESSURE DATA. VAPOR PRESSURE DATA FROM REFERENCE 11.

EXPERIMENTS ON VAPOR PRESSURE LOWERING

Equation (2) offered itself as a medium for evaluating capillary pressures at low saturation values and high values of the capillary pressure. With this in mind an apparatus was constructed to measure the difference in vapor pressure above a flat surface of water and that within a porous body at partial water saturation. The apparatus used is diagrammed in Fig. 2. Although it was not sufficiently sensitive to detect small changes in vapor pressure, it sufficed to give accuracy over the range of saturation. The porous media employed were composed of consolidated quartz. They were manufactured in the laboratory by consolidating sand grains with silica by deposition from colloidal suspension and by the hydrolysis of tetraethyl orthosilicate. The sand grains before consolidation were in the sieve

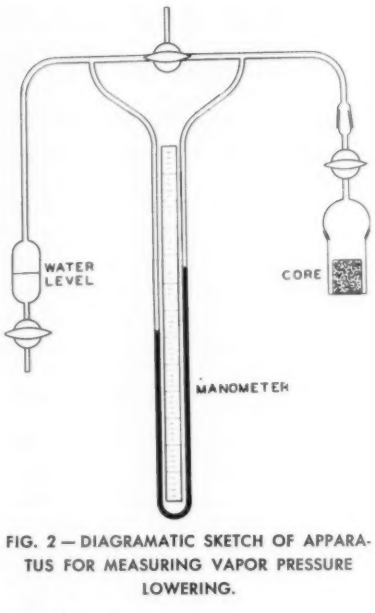

FIG. 2 — DIAGRAMATIC SKETCH OF APPARATUS FOR MEASURING VAPOR PRESSURE LOWERING.

range, 140-170.

Data were taken on four separate cores. They were first saturated fully with water and by the use of a conventional type capillary pressure cell

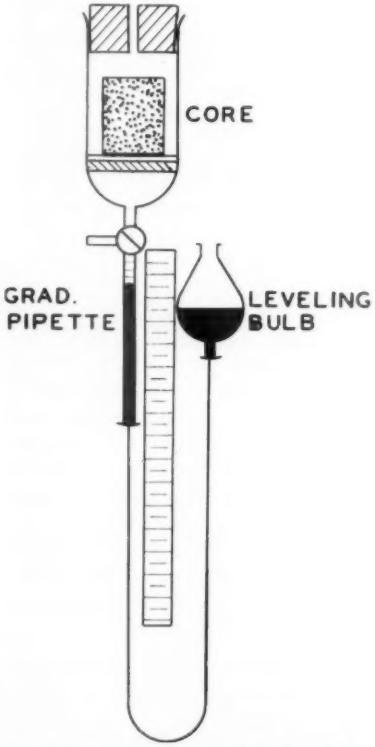

FIG. 3 — DIAGRAMATIC SKETCH OF APPARATUS FOR MEASURING CAPILLARY PRESSURES BY DISPLACEMENT.

(shown in Fig. 3) the capillary pressure curve for each core was determined in a routine fashion. The core was then placed in the vapor pressure apparatus, maintained at a constant temperature of 97°F., where further desaturation was accomplished by evacuating water vapor from the core side of the system. After sufficient evacuation had taken place, the system was closed and allowed to come to equilibrium, after which the manometer read directly the amount of vapor pressure lowering. Saturations were determined by removing and weighing that portion of the assembly which contained the core. It was necessary after each weighing to purge the apparatus of the air which entered when the assembly was unjointed for the weighing.

Both the routine capillary pressure data and the vapor pressure lowering data are given in Table 1. In Fig. 4 are plotted curves which show the data taken by the customary method of obtaining capillary pressures for the cores listed in Table 1 and for several other similar cores. The curves of Figs. 5, 6 and 8 show the capillary pressure data calculated from the vapor pressure calculated from the vapor pressure pressure data shown in Fig. 4. The logarithm scale is used to permit showing the high values and at the same time showing the lower plateau region. One experimental point on two of these curves was determined neither with the apparatus of Fig. 2 nor Fig. 3 but by means of an applied air pressure above

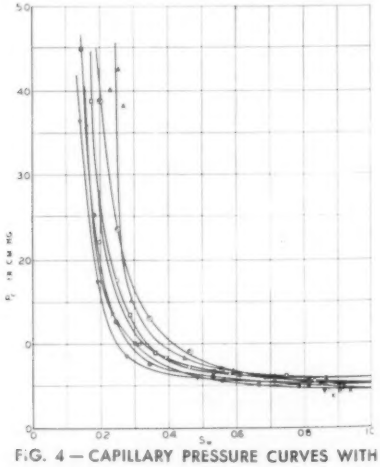

FIG. 4 — CAPILLARY PRESSURE CURVES WITH AIR DISPLACEMENT; ○ CORE NO. 2; ▽ CORE NO. 3; □ CORE NO. 5; ● CORE NO. 6; ⊡ CORE NO. 8; △ CORE NO. 9; X CORE NO. 10.

TABLE 1

Capillary Pressure Data by Routine Displacement and by Vapor Pressure Lowering

Core #2 K=2100 md. φ=0.322			Core #3 K=855 md. φ=0.291			Core #6 K=760 md. φ=0.279			Core #8 K=3000 md. φ=0.321		
Sw	Pvo/Pv	Pc Cm Hg	Sw	Pvo/Pv	Pc Cm Hg	Sw	Pvo/Pv	Pc Cm Hg	Sw	Pvo/Pv	Pc Cm Hg
0.830		5.43	0.712		5.38	0.811		5.05	0.856		5.19
0.603		6.19	0.486		5.93	0.530		6.02	0.691		5.89
0.578		6.34	0.276		8.48	0.343		7.51	0.558		6.86
0.459		7.05	0.192		17.46	0.246		12.60	0.464		8.99
0.394		8.26	0.142		36.4	0.181		25.3	0.346		13.0
0.361		8.85	0.0962	1.052	5,430	0.146		45.0	0.252		23.6
0.315		9.93	0.0744	3.289	127,000	0.144		305.0	0.201		38.8
0.248		17.6	0.0668	4.367	158,000	0.103	1.101	10,250	0.121		305.0
0.197		22.1	0.0560	6.369	198,000	0.079	3.344	129,000	0.0909	1.337	31,000
0.0667	1.304	28,350	0.0533	11.111	257,000	0.069	4.796	168,000	0.0798	1.782	61,900
0.0549	2.016	75,000	0.0407	20.833	325,000	0.058	7.692	217,000	0.0676	2.941	116,000
0.0527	2.066	77,500				0.0536	9.709	243,000	0.0570	3.922	147,000
0.0493	2.155	82,000				0.0479	19.157	316,000	0.0496	5.917	191,000
						0.0382	28.903	360,000	0.0487	9.346	239,000
						0.0325	37.313	387,000	0.0375	10.526	252,000
									0.0319	24.096	340,000

a diaphragm on which the core was placed. These are the data at approximately 300 cm. Hg. on cores No. 6 and No. 8.

Although no overlap of data between the vapor pressure method and the routine displacement was procured, the data give, in each case, continuous curves from one hundred per cent saturation to zero saturation.

A significant point to this correlation is that there is, strictly speaking, no absolute irreducible minimum of saturation. All of the curves turn into the zero saturation axis at a finite positive capillary pressure. Fig. 9 shows an expanded plot of the capillary pressures in the lower saturation region as calculated from the vapor pressure data. Within the range of average reservoir pressures, however, there is a saturation plateau, which from a practical view point is equivalent to an irreducible minimum. However, this plateau is reached at capillary pressures somewhat above those normally taken as the maximum in routine laboratory work. From Fig. 4, for example, on all cores it appears that the irreducible minimum saturation would be approximately that saturation shown at the highest capillary pressure, which is about 45 cm. Hg. As shown by Figs. 5 to 8, however, all of these cores at a capillary pressure of 45 cm. Hg. are several per cent away from the saturation plateau.

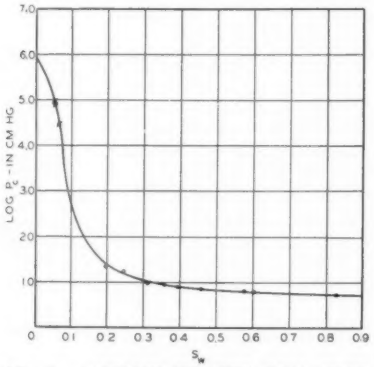

FIG. 5 — CAPILLARY PRESSURE DATA CORE NO. 2 ○ DETERMINED BY DISPLACEMENT; φ DETERMINED BY VAPOR PRESSURE LOWERING.

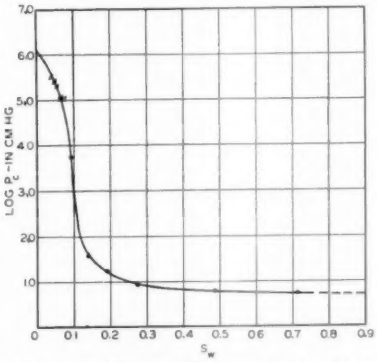

FIG. 6 — CAPILLARY PRESSURE DATA CORE NO. 3 ○ DETERMINED BY DISPLACEMENT; φ DETERMINED BY VAPOR PRESSURE LOWERING.

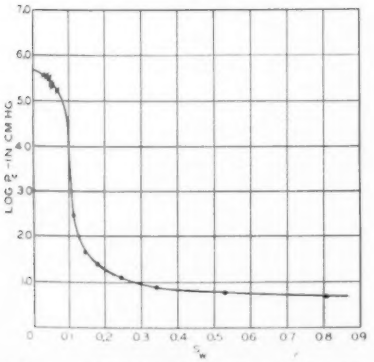

FIG. 7 — CAPILLARY PRESSURE DATA CORE NO. 6 ○ DETERMINED BY DISPLACEMENT; φ DETERMINED BY VAPOR PRESSURE LOWERING.

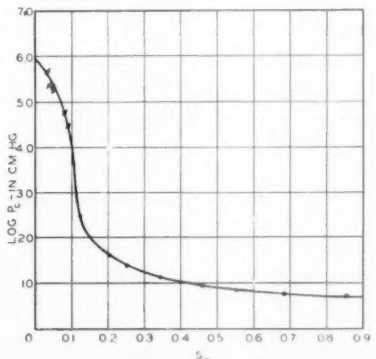

FIG. 8 — CAPILLARY PRESSURE DATA CORE NO. 8 ○ DETERMINED BY DISPLACEMENT; φ DETERMINED BY VAPOR PRESSURE LOWERING.

DISPLACEMENT WITH VARIOUS LIQUIDS

It is common to use the capillary displacement of water by air as a measure of the connate wate content of a given reservoir material. Following Leverett's presentation of capillary pressure in the form

$$P_c = \delta \sqrt{\frac{\Phi}{K}}\, J(S_w) \quad \cdots\cdots\cdots \quad (3)$$

it has been suggested that, with two different displacing fluids, the ratio of capillary pressures for a given value of water saturation would be the ratio of the δ values. Work with systems other than air-water have been reported by several authors. Hassler, et al[2] did not find a constant ratio as expected. Purcell,[6] whose work was done with mercury, gives good correlations between capillary pressure curves with water and with mercury using a ratio of $\delta \cos\theta$ values rather than a ratio of δ values. Bruce and Welge[3] give a series of different irreducible water saturations using air and oil displacement.

In the present work several different pure liquids were used to displace distilled water from three of the laboratory prepared silica porous bodies. Liquids used were toluene, benzene, cyclohexane, tetradecane, and oleic acid. Air was used as a displacing medium as

TABLE 2

Capillary Pressure Data Obtained by Displacement with Various Fluids

Core 1 — L K = 1.22 Darcys ϕ = .249

Air		Tetradecane		Oleic Acid		Toluene		Benzene		Hexane	
P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w
1.6	98.01	0.5	98.80	0.2	99.08	1.7	88.1	0.8	99.19	1.43	98.89
2.7	96.46	1.4	93.38	0.3	96.63	2.1	76.0	1.3	96.60	1.74	90.11
3.4	91.22	2.1	84.4	0.7	91.73	2.4	57.7	1.4	91.68	2.14	77.20
4.2	79.0	2.4	71.7	0.9	82.9	2.7	44.7	1.5	88.9	2.54	68.80
5.1	68.3	2.7	56.3	1.0	64.5	3.0	33.3	1.6	83.7	3.40	47.30
6.2	41.6	3.4	36.1	1.3	45.8	4.1	30.0	1.7	80.6	5.65	45.20
8.6	24.7	4.7	23.3	1.6	32.4	5.8	28.8	1.9	72.2	14.4	39.50
15.4	22.9	8.1	21.4	2.0	26.0	9.8	28.0	2.0	70.4	14.7	40.20
23.9	20.3			7.7	19.9	15.8	22.3	2.1	67.3	15.2	41.00
						16.0	22.6	2.2	65.4	15.7	42.10
								2.7	62.0	16.3	43.00
								2.9	58.0	16.6	43.60
								3.4	55.0	16.5	43.30
								7.3	54.3	16.7	43.90
								23.9	53.7	16.6	43.90
										16.8	44.20

TABLE 3

Capillary Pressure Data Obtained by Displacement with Various Fluids

Core 2 — L K = 1.83 Darcys ϕ = .251

Air		Tetradecane		Oleic Acid		Cyclohexane		Toluene	
P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w
1.7	96.25	0.4	98.82	0.6	92.88	0.5	98.10	0.8	98.16
3.2	83.7	1.1	97.04	0.7	85.9	0.7	92.66	1.0	92.61
3.5	72.8	1.3	89.1	0.9	59.9	1.0	80.5	1.5	79.1
3.8	56.7	1.6	77.5	1.0	47.0	1.2	69.1	1.6	67.2
4.1	45.9	2.2	62.2	1.2	30.0	1.6	51.3	2.2	51.5
4.4	36.6	2.7	39.0	2.3	22.8	2.1	40.8	2.5	41.4
4.9	27.7	3.4	29.6	5.4	20.2	2.2	33.6	4.9	28.2
8.4	21.8	5.8	25.0	10.0	19.7	3.5	25.5	7.2	27.7
14.2	20.9	10.1	20.5			5.3	21.6	16.0	25.9
14.4	20.4	15.6	19.3			10.2	20.0	24.3	25.7
		20.6	18.0			16.9	19.0		
						16.7	18.5		

TABLE 4

Capillary Pressure Data Obtained by Displacement with Various Fluids

Core 3 — L K = 1.11 Darcys ϕ = .258

Air		Tetradecane		Oleic Acid		Hexane	
P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w	P_c Cm Hg	S_w
0.8	98.40	0.6	99.04	0.7	91.60	0.1	99.08
1.8	97.69	1.9	95.20	0.75	77.4	2.2	94.20
3.2	95.13	2.5	72.7	1.1	61.5	3.0	83.4
5.0	79.0	3.8	51.7	1.3	48.8	3.5	70.8
5.7	66.6	4.3	33.4	2.2	35.2	3.8	56.7
6.9	44.9	6.0	24.5	2.9	26.6	4.2	41.3
8.8	33.3	8.0	19.0	4.9	20.7	4.4	35.0
12.1	20.5	12.1	18.0	7.3	18.7	6.9	27.2
15.9	19.8	17.4	17.1			14.5	25.8
25.3	16.6					14.7	26.5
						15.2	27.5
						16.1	28.9
						17.0	30.8

well. Saturations were determined by the volumetric measurement of the amount of displaced saturant in an apparatus similar to that shown in Fig. 3. The results of these tests are given graphically in Figs. 10, 11 and 12. Tables 2, 3 and 4 list the data taken in chronological sequence. Not shown in these tables are several duplicate runs made with several of the displacing liquids.

The irreducible water saturations which were attained were approximately equivalent on each core with the exceptions of benzene displacement on core 1-L, toluene displacement on cores 1-L and 2-L, and hexane displacement on cores 1-L and 3-L. There is some basis for believing that these apparently high values were due to faulty technique because there was on some of these particular tests an apparent regression of the desaturation process. It could also be true that the apparently high values of saturation found by displacement with these fluids is a manifestation of a

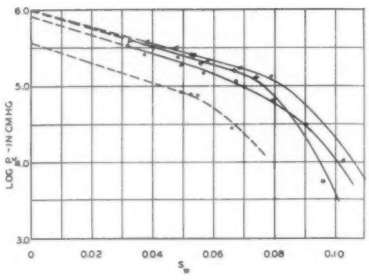

FIG. 9 — EXPANDED PLOT SHOWING CAPILLARY PRESSURES AT EXTREMELY HIGH VALUES.

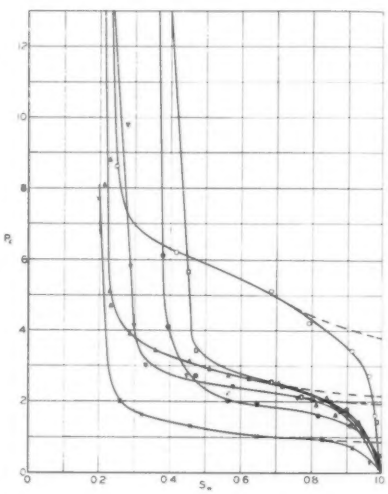

FIG. 10—CAPILLARY PRESSURE CURVES CORE NO. 1-L; DISPLACEMENT OF WATER WITH VARIOUS FLUIDS. o AIR; △ TETRADECANE; x OLEIC ACID □ HEXANE; ▽ TOLUENE; • BENZENE.

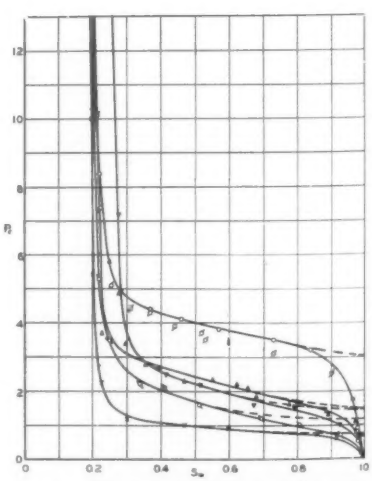

FIG. 11—CAPILLARY PRESSURE CURVES CORE NO. 2-L. DISPLACEMENT OF WATER WITH VARIOUS FLUIDS; o AIR, FIRST RUN; ϕ AIR, SECOND RUN;; △ TETRADECANE; x OLEIC ACID; Φ CYCLOHEXANE; ▽ TOLUENE.

true characteristic of these core systems.

Interfacial tensions between water and the various liquids were measured with the du Nouy tensiometer and values were also taken from the International Critical Tables. This data is given in Table 5. It is apparent from these measurements that impurities may have been present in some of the liquids which were employed.

TABLE 5
Interfacial Tensions
(Dynes per centimeter)
Temperature = 36°C.

Consecutive Readings	Liquid System						
	δ Water-Air	δ Water-Tetradecane	δ Water-Toluene	δ Water-Benzene	δ Water-Oleic Acid	δ Water-Hexane	δ Water-Cyclohexane
1	70.2	32.5	26.3	24.6	8.5	45.7	31.5
2	70.0	31.7	26.2	24.6	8.5	45.6	28.5
3		31.7	25.9	25.4	8.4	45.8	24.3
4		31.4	25.7	23.7	7.2	45.1	25.1
5		31.4	25.7	23.6	7.8	46.5	23.1
6						45.7	21.5
7							13.7
8							14.4
9							13.8
10							12.6
11							11.5
12							9.8
13							9.2
14							8.8
15							9.4
International Critical Tables			36.1 (25°C.)	35.00 (25°C.)	15.59 (20°C.)	51.1 (25°C.)	

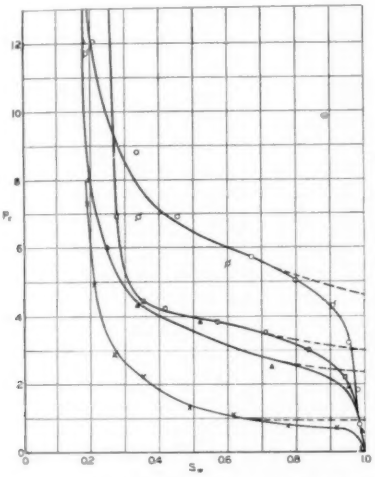

FIG. 12—CAPILLARY PRESSURE CURVES CORE NO. 3-L. DISPLACEMENT OF WATER WITH VARIOUS FLUIDS; o AIR; FIRST RUN; ϕ AIR, SECOND RUN; □ HEXANE; △ TETRADECANE; x OLEIC ACID.

For a given water saturation, values of capillary pressure with air displacing divided by the values for liquid displacing were always greater than unity. These ratios are shown in Figs. 13 and 14. The dotted lines on the graphs show the ratios of the interfacial tension for air against water to that of the given liquid against water. In some instances, there is excellent agreement between the measured ratios and theoretical ratios, in particular, hexane on core No. 3-L, benzene on core No. 1-L and tetradecane on core No. 1-L. In the majority of instances, although the ratios at 100% saturation are near the expected theoretical values the ratios show a decrease as desaturation proceeds. There is no readily apparent explanation for this drop in ratio.

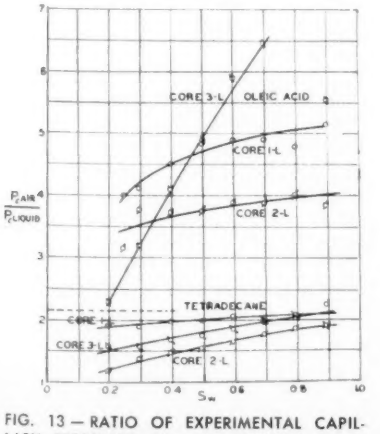

FIG. 13 — RATIO OF EXPERIMENTAL CAPILLARY PRESSURES AND COMPARISON WITH INTERFACIAL TENSION RATIOS.

Theoretical Correlations:

In recent publications it has been suggested, and the suggestions have been supported to a certain degree by experimental data, that definite correlations can be obtained between various fundamental measurable quantities of porous bodies. Purcell[5] has offered the following equation to compute the permeability from capillary pressure data:

$$K = \frac{F\,\delta^2\,\Phi\,\cos^2\theta}{2}\int_0^{1.0}\frac{dS_w}{P_c^2} \quad \cdots\cdots (4)$$

Rose[8] has developed certain relative permeability concepts on the basis of the Kozeny equation which he gives as:

$$K = \frac{\Phi}{A^2 t} \quad \cdots\cdots (5)$$

Rose furthermore states that from Leverett's J (Sw) function the following is true:

$$\lim_{S_w \to 1.0} J(S_w) = \left(\frac{1}{t}\right)^{1/2} \quad \cdots (6)$$

The J (Sw) function as given by Leverett is equation (3). To extend its applicability to all liquids it is now written as:

$$J(S_w) = \frac{P_c}{\delta\,\cos\theta}\sqrt{\frac{K}{\Phi}} \quad \cdots\cdots (7)$$

The value of the capillary pressure as the saturation approaches unity is the displacement pressure, P_D. At this limit, equation (7) is:

$$J(S_w)_{1.0} = \frac{P_D}{\delta\,\cos\theta}\sqrt{\frac{K}{\Phi}}$$

This can be rearranged to give an expression for the permeability. Thus:

$$K = \frac{[J(S_w)_{1.0}]^2\,\Phi\,\delta^2\,\cos^2\theta}{P_D^2} \quad \cdots (8)$$

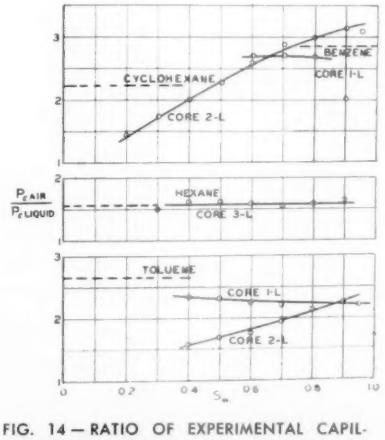

FIG. 14 — RATIO OF EXPERIMENTAL CAPILLARY PRESSURES AND COMPARISON WITH INTERFACIAL TENSION RATIOS.

Comparing equations (8) and (5) and considering equation (6) the following equality is found:

$$A^2 = \frac{P_D^2}{\delta^2 \cos^2 \theta}$$

For a straight bore capillary this equality is known to be true. A is defined as the surface area per unit of pore space which, for a capillary of radius R and length L, would be:

$$A = \frac{2 \pi RL}{\pi R^2 L} = \frac{2}{R}$$

The displacement pressure is, in terms of R:

$$P_D = \frac{2 \delta \cos \theta}{R} = A\delta \cos \theta \quad \cdots \quad (9)$$

which is the equation given above.

Comparing equation (8) with equation (4) gives the following equality:

$$\frac{F}{2} \int_0^{1.0} \frac{d\, S_w}{P_c^2} = \frac{[J (S_w)_{1.0}]^2}{P_D^2} \quad (10)$$

An examination of the data presented in this report leads to the conclusion that:

$$\frac{1}{P_D^2} = 2 \int_0^{1.0} \frac{dS_w}{P_c^2} \quad \cdots \cdots \cdots \quad (11)$$

which then produces the equalities that follow:

$$F = 4[J (S_w)_{1.0}]^2 \quad \cdots \quad (12)$$

or $$F = \frac{4}{t}$$

and also

$$\frac{1}{A^2} = 2\delta^2 \cos^2 \theta \int_0^{1.0} \frac{dS_w}{P_c^2} \quad \cdots \quad (13)$$

Equation (11) is given as a result of observations made on the data given in Tables 1, 2, 3 and 4. There is no readily apparent theoretical basis for the relationship. In examining the data of Table 7 for air displacement only, the capillary pressure curves were converted to plots of the reciprocal of P_c^2 versus S_w similar to that of Figure 15. These were then planimetered to obtain the values of the integral and from the relationship of equation (11) values of P_D were calculated. Values of the integral and P_D values are listed in Table 6. Comparison is also given in Table 6 between the calculated values of P_D and those read from the curves of Fig. 4 by extrapolation to a saturation of 1.0.

TABLE 6

Core No.	Displacing Fluid	$\int_0^{1.0} \frac{dS_w}{P_c^2}$ Cm^{-2}	Calc. P_D Cm Hg	Observed P_D Cm Hg	A Cm^2/Cm^3	A (Carman Method) Cm^2/Cm^3
2	Air	.0186	5.18	5.20	960	840
3	Air	.0223	4.72	5.15	872	1120
5	Air	.0181	5.25	5.30	970	1125
6	Air	.0228	4.68	4.60	866	1115
8	Air	.0172	5.40	4.70	998	705
9	Air	.0158	5.62	5.80	1,040	920
10	Air	.0252	4.45	4.50	823	364

TABLE 7

Core No.	Displacing Fluid	$\int_0^{1.0} \frac{dS_w}{P_c^2}$ Cm^{-2}	Calc. P_D Cm Hg	Calc. $\delta \cos \theta$ dynes/cm	A Cm^2/Cm^3
1-L	Air	.0278	4.25		785
	Tetradecane	.109	2.14	36.2	
	Oleic Acid	.710	0.84	14.25	
	Toluene	.139	1.90	32.2	
2-L	Air	.056	2.99		554
	Tetradecane	.228	1.48	35.6	
	Oleic Acid	.890	0.75	18.0	
	Toluene	.234	1.46	35.1	
	Cyclohexane	.362	1.18	28.3	
3-L	Air	.023	4.62		854
	Tetradecane	.090	2.35	36.6	
	Oleic Acid	.560	0.945	14.7	
	Hexane	.056	2.99	46.5	

The data of Tables 2, 3 and 4 were also replotted to give curves similar to Fig. 15. Agreement with equation (11) was obtained for this data by noting the values of P_D which balanced the equation. The values are given in Figs. 10, 11 and 12. On these graphs the dashed lines are drawn to indicate the curve which satisfies equation (11). In Table 7 are listed the integral values and the calculated values of P_D. The values of $\delta \cos \theta$ in Table 7 were obtained from the calculated values of P_D by reference to the value of P_D for air displacing water, in which case the contact angle was assumed to be zero.

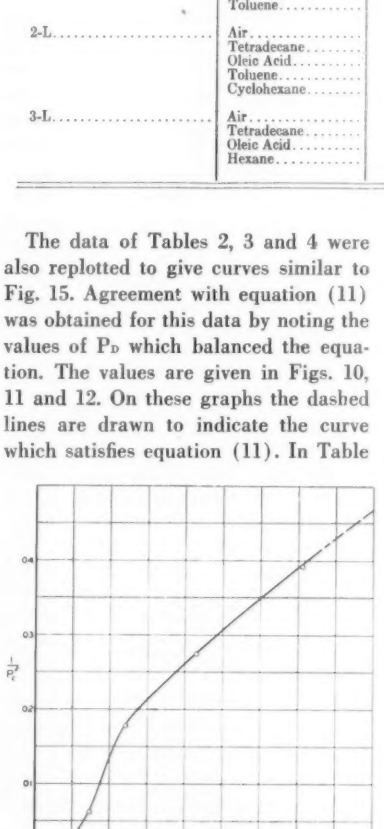

FIG. 15 — TYPICAL GRAPH FOR DETERMINATION OF $\int_0^{1.0} \frac{dS_w}{P_c^2}$

It is of interest to note that the values of $\delta \cos \theta$ are in good agreement with the previously tabulated value of δ. The fact that the agreement is close indicates that in every instance the contact angle was probably zero or approximately zero.

The internal surface area of the porous bodies was found by equation (9). Calculated values of P_D and $\delta \cos \theta$ were used rather than the experimental values for this determination. The surface area values so found are given in Tables 6 and 7.

It is possible also to determine the internal surface area from the vapor pressure data which was taken. The following equation is given without deriviation as being applicable to the adsorption of a liquid within a porous material:[12]

$$\frac{P_v}{V(P_{vo}-P_v)} = \frac{1}{V_mC} + \frac{C-1}{V_mC}\,\frac{P_v}{P_{vo}} \quad (14)$$

where V_m = the volume of water adsorbed in a single layer on the entire porous surface.

V = the volume of water adsorbed at the pressure, P_v

P_{vo} = the vapor pressure of water above a flat surface

C = a constant.

Thus, by plotting the obtained vapor pressure data in the form of equation (14) the slope and intercept of the expected linear plot will suffice to calculate V_m. A knowledge of the space covered by a single water molecule suffices then to calculate the surface area covered. Figs. 16, 17 and 18 show the adsorption data for three cores as given in Table 1 plotted according to equation (14), using weights of water adsorbed in place of volumes. Assuming that one water molecule covers an area of 11.5×10^{-16} cm^2, the total surface is calculated in the three instances as 204, 228, and 172 square meters per cubic centimeter of void space. Values for the surface area as given in Table 6 for these cores are 872, 866, and 998 square centimeters per cubic centimeter of void space. The latter values are more in agreement with that which would be expected for uniformly packed spheres than are the former.

A third method of obtaining the internal surface area of these core specimens would be by use of the relationship:

$$A = \frac{-1}{\delta_{S\text{-}W} - \delta_{S\text{-}A}} \int_0^{1.0} P_c\, dS_w \quad - \quad (15)$$

Leverett[1] has given the free surface energy change per unit of pore volume between two different saturations of the same core as:

$$\Delta F = -\int_{S_{w1}}^{S_{w2}} P_c dS_w$$

By choosing the limits of saturation as zero and one hundred per cent the surface energy change is:

$\Delta F = A\delta_{S\text{-}W} - A\delta_{S\text{-}A}$

because the unit free surface energy when the core is dry is $\delta_{S\text{-}A}$ and the unit free surface energy when the core is fully saturated is $\delta_{S\text{-}W}$. Combining the two expressions for ΔF gives equation

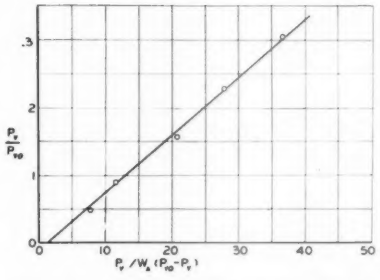

FIG. 16 — VAPOR PRESSURE DATA PLOTTED AS WATER ADSORPTION FOR DETERMINATION OF SURFACE AREA. CORE NO. 3.

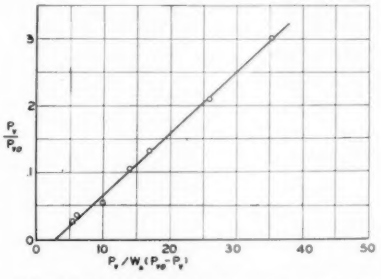

FIG. 17 — VAPOR PRESSURE DATA PLOTTED AS WATER ADSORPTION FOR DETERMINATION OF SURFACE AREA. CORE NO. 6.

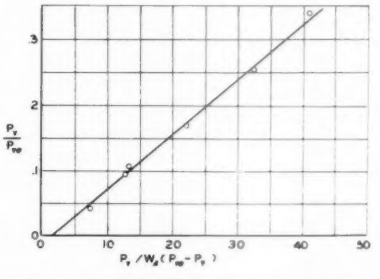

FIG. 18 — VAPOR PRESSURE DATA PLOTTED AS WATER ADSORPTION FOR DETERMINATION OF SURFACE AREA. CORE NO. 8.

(15). This equation cannot be used to solve for A because the interfacial tension values are not known. It could be used to obtain the difference in the interfacial tensions if A and the value of the integral were known. This has been done for cores Nos. 3, 6 and 8, for which the capillary pressure function is complete from zero to full saturation. A choice of the most logical A value was necessary for this calculations. Using the values obtained from the vapor pressure data yields values of $(\delta_{S\text{-}A} - \delta_{S\text{-}W})$ of 214, 204, and 206 dynes per centimeter. Using the lower values of A would have given negligible differences.

Bartell[13] has defined the above difference in interfacial tensions as the adhesion tension and for the system silica-water he gives the value of $(\delta_{S\text{-}A} - \delta_{S\text{-}W})$ to be 75.1 dynes per centimeter. It would appear from this that the A values as calculated by the adsorption method were too large.

Carman has evaluated the surface area of powders by a method based upon permeability and porosity measurement, a discussion of which method is given by Brunauer[12]. Using this method and the experimentally determined porosity and permeability values specific surface areas were calculated. These are listed in Table 6. It will be noted that they do not agree numerically with A values calculated from P_D but the two are comparable in magnitude.

It is apparent that two different surface area values are being measured. So far as flow properties and total void space are concerned the roughness of the internal surfaces will not be apparent. With the measurement of wettability and adsorption phenomena the intricacies of the surface will be apparent. The adsorption measurement should give the higher values of A where there is roughness or etching of the internal surfaces. In the particular measurements reported here the porous bodies were prepared by consolidating sand grains by depositing silica from colloidal suspension and by the hydrolysis of tefraethylorthosilicate. This deposition is in the form of fine flaky particles, a condition which would enhance the amount of surface area which would be evident from a wettability or adsorption measurement.

SUMMARY AND CONCLUSIONS

The experiments reported here lead one to the conclusion that for the practical purpose of obtaining connate water values by capillary pressure curves, caution should be used in choice of a displacing liquid. The experiments demonstrate the desirability of determining such values at a maximum pressure which is a considerable distance above the capillary pressure plateau. From a strictly theoretical standpoint the experiments indicate that there is no "irreducible minimum" and that zero water saturation is reached at some finite value of capillary pressure.

The possible usefulness of vapor pressure measurements or adsorption

data to give characteristics of porous reservoir materials has been outlined. Good agreement was obtained between capillary pressure data by displacement and that calculated from the vapor pressure data.

Following the lead of previous authors, the capillary pressure data have been used to characterize the individual porous systems. It has been shown that the displacement pressure bears a definite relationship to $\int \frac{d\ S_w}{P_c^2}$.

Surface area values were calculated from the displacement pressures, from the adsorption data and from the Carman equation. It is apparent that difference quantities are being measured by the different methods.

ACKNOWLEDGMENTS

The experimental work which is reported in this paper was performed by Mr. Newman and Mr. Lewis while they were graduate students in Petroleum Engineering at the University of Oklahoma. Further details of their work is embodied in the theses which they submitted in partial fulfillment of requirements for the Master's degree. During this period Mr. Newman held the Phillips Petroleum Company Fellowship in Petroleum Engineering and Mr. Lewis held the Shell Oil Company Fellowship in Petroleum Engineering. The authors wish to express their deep appreciation for this support, without which their work would have been seriously curtailed.

NOMENCLATURE

- P_c = Capillary pressure
- P_D = Displacement pressure
- P_v = Vapor phase pressure at equilibrium
- P_{vo} = Equilibrum vapor pressure above a flat liquid surface
- P_l = Liquid phase pressure at equilibrium
- ρ_v = Vapor phase density
- ρ_l = Liquid phase density
- h = Height above a free water surface
- M = Molecular weight
- R = Gas constant
- T = Temperature of porous solid system
- Φ = Porosity as a fraction
- K = Permeability
- S_w = Water saturation, fractional
- δ = Interfacial tension
- $\delta_{S\text{-}A}$ = Interfacial tension, silica air
- $\delta_{S\text{-}W}$ = Interfacial tension, silica water
- θ = Contact angle
- $\triangle F$ = Free surface energy change per unit pore volume
- A = Internal surface area
- F = Lithology factor as defined by Purcell
- t = Tortuosity constant in Kozeny equation

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FACTORS INVOLVED IN REMOVAL OF SULPHATE FROM DRILLING MUDS BY BARIUM CARBONATE

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ABSTRACT

The conditions under which barium carbonate can be used to remove sulfates from drilling muds are limited The amount of sulfate remaining in solution in the system after treatment with barium carbonate is shown to be a function of the concentration of the carbonate and barium ions and the concentration of other electrolytes. Barium hydroxide may advantageously replace barium carbonate when the contamination is not entirely due to anhydrite (calcium in the system is then stoichiometrically less than sulfate) or when the carbonate concentration is high. The effect of substances such as quebracho, phosphates, and chromates, which form complexes or precipitates with barium, is discussed.

INTRODUCTION

As the complexity of the operations in drilling for oil has increased, more attention has of necessity been directed to the problems pertaining to the maintenance of good drilling mud properties. As a result, chemical treatment of muds has become an important factor in recent years. Some of these treatments have been designed to eliminate the deleterious effects of contaminants in aqueous mud systems by precipitation or other means. The most common of substances encountered during drilling include sodium chloride, cement, and calcium sulfate while various other contaminants, usually in small amounts, may be introduced from the water, clays, and other materials used in preparation of the mud. In certain cases, for example where continued salt-water flow is encountered or massive anhydrite is drilled, special muds may be used so that the physical properties of the mud will remain satisfactory for drilling. In other cases, it is desirable to remove the contaminants so that soluble electrolytes in the system are maintained at low values.

For sulfate contamination, the common practice in the field is to add barium carbonate to precipitate the sulfate as barium sulfate[1,2]. Ordinarily such a procedure gives satisfactory results. There have been important instances, however, where addition of barium carbonate was not effective in removal of soluble sulfates from drilling muds, and it is to these cases that the present paper is directed.

While it is generally known that barium carbonate is not always effective in removing soluble sulfates from drilling muds, certain inconsistencies appear in the literature as to the limitations of its use, and little explanation for the limitations are given. Varnell and Kimbrell[3] state that "the treatment (with barium carbonate for removal of sulfate) is simple and consists in maintaining a pH of 9 with caustic soda and quebracho." They caution that concentrations of quebracho greater than 1 lb./bbl. may inhibit the reaction. In another publication[4], a pH of 10.5 is considered "the maximum desirable," and the indication is that as much as 2.5 lb. quebracho per barrel may be present in the particular mud under discussion. Lancaster and Mitchell[5] state that appreciable amounts of phosphates in the mud will inhibit the reaction with barium carbonate and that the phosphate treatment should be discontinued at least 24 hours before addition of the carbonate.

Experimental work was initiated to ascertain the factors involved in using barium carbonate for the removal of sulfate contamination in drilling muds. While the experimental data herein reported are limited, they focus attention on the pertinent factors which must be considered for successful treatment. These factors are discussed from a practical and a theoretical view, the latter being supported by equilibrium data found in the literature. Further, it will be appreciated that the factors involved in this specific study will be closely analogous to those in certain of the other chemical treatments which involve a precipitation of the soluble contaminant. A thorough comprehension of these factors should result in a more fruitful application of this type of chemical reaction to the treatment of drilling muds.

EXPERIMENTAL

A. Reagents

Two muds were used during this investigation. For one series of tests, bentonite suspensions were prepared by dilution of a stock suspension containing 8 per cent by weight of bentonite (Aquagel). For another series, a 6.4 per cent bentonitic mud weighted to 9.7 lb./gal. with barium sulfate (Magcobar) was used. Distilled water was used in all preparations.

The quebracho (72% tannin extract) was obtained from the Thompson-Hayward Co. of Tulsa and contained 11.4 per cent moisture (105 C.).

All other materials were reagent grade, and concentrations were corrected for water of crystallization, if any. All concentrations are expressed in pounds per barrel (42 gallons).

B. Technique

The systems — either mud or water — were contaminated with either sodium or calcium sulfate after treatment with the desired amounts of sodium hydroxide and quebracho. For treatments with barium carbonate an approximately 3-fold excess (5 lb./bbl.) was used over that computed to be required to precipitate all the sulfate as barium sulfate. Barium hydroxide was used in concentrations of 2 lb./bbl. — about

Manuscript received at office of Petro'eum Branch August 16, 1949. Paper presented at Branch Fall Meeting in Dallas October 4-6, 1948.
[1] References are given at end of paper.

1.6 times that required to precipitate the sulfate. An error of about one per cent was involved in preparing these systems.

The treated suspensions were aged in sealed bottles at room temperature (about 25 C.) or at 95 C. for various periods of time. The suspensions were stirred intermittently during all prolonged aging periods and continuously for all 0.5 hour aging periods. At the end of the desired aging period, the muds were filtered on Baroid presses at 100 psi gage, while other systems were filtered twice without pressure through Whatman No. 42 paper (for fine-grained precipitates). For these latter experiments — no clay present — some very fine material would pass through the filter paper even after four filtrations through the same filter. Consequently, the filtrates were allowed to settle about one hour, and the supernatant liquid was taken for analysis.

The physical properties of the muds were determined in accordance with the procedure given in A.P.I. Code 29. The muds were stirred 30 minutes with a high speed mixer before conducting these tests.

The sulfate was determined by evaporating aliquots of the filtered solutions, acidified with HCl, to dryness and then extracting the residue with hydrochloric acid. The extract was then filtered and the soluble sulfate was precipitated with barium chloride. The precipitated barium sulfate was ignited and weighed. It should be mentioned that this procedure determines only that soluble sulfate which is present in excess of soluble barium and hence gives a *minimum value* for the soluble sulfate which is present in the system.

EXPERIMENTAL RESULTS AND DISCUSSION

One of the factors which was considered to be one of some importance in the effectiveness or at least the rate of precipitation of sulfate by barium carbonate, was that the barium carbonate might become coated with clay and not be solubilized at an appreciable rate. This effect, if real, would be of significance particularly in any system having a low water-loss value. By using concentrations of bentonite from 0 to 8 per cent with calcium sulfate as contaminant in fixed amount (1 lb./bbl.) the water-loss values were varied between 6.5 and 44 ml./30 min. The results of the tests (Table I) show that water-loss value has no close relationship to the effectiveness of the barium carbonate. The barium carbonate treatment decreased the sulfate to about 154 ppm. within 0.5 hour as compared to values of 21 to 49 ppm. achieved with barium hydroxide. After aging the suspensions at 95 C. for 20 hours the sulfate was reduced to 50 $\pm$ 25 ppm. in all cases.

It will be noted that the control tests (No. 3, 6, and 8 of Table I) show increasing sulfate concentrations with increase in concentration of bentonite. This is explained by the fact that the concentration of added sulfate is based on volume of mud and not on volume of water. The values for sulfate agree within experimental error with those computed for the amount present per unit volume of water corrected for a small amount present as impurity in the clay.

The next tests (Table II) were intended to show possible limits both for the pH of the mud and the concentration of quebracho required to render the barium carbonate ineffective for the removal of sulfate. At the same time, a comparison was made between the effects when using barium hydroxide and the carbonate. The bentonitic mud was treated with various amounts of caustic and quebracho and contaminated with calcium sulfate (1 lb./bbl). The sulfate in the filtrate from the muds was determined after the muds had aged 16 hours at 95 C. The physical properties (A.P.I. Code 29) were also determined for the aged muds.

The results of these tests (Table II) show that the barium carbonate reduced the sulfate to 245 $\pm$ 25 ppm. in the low pH systems (Parts A and B of Table II), but was essentially ineffective in the high pH systems (Parts B and C). The fact that the quebracho in amounts greater than 1 lb./bbl. was not completely solubilized before aging the mud at pH 8.3 precludes any definite conclusion regarding the effect of the quebracho. In the high pH, high quebracho systems, the ineffectiveness of the barium carbonate could be attributed to either the pH or the quebracho. The results definitely prove that an initial pH of 12.4 is sufficiently high to render the

TABLE I

Removal of Sulfate with Barium Carbonate and Barium Hydroxide from Bentonite Suspensions

Test No.	Bentonite, % by wt.	$CaSO_4$, lb/bbl	$BaCO_3$ lb/bbl	$Ba(OH)_2$, lb/bbl	pH of Mud		Water-loss of Treated Suspension*, ml/30 min.	ppm $SO_4^=$ in filtrate from	
					Mud Aged 0.5 hr. at 25° C.	Mud Aged 20 hr. at 95° C.		Mud Aged 0.5 hr. at 25° C.	Mud Aged 20 hr. at 95° C.
1	0	1.0	5.0	—	8.8	9.5	—	177	25
2	1.14	1.0	5.0	—	8.7	9.6	44	165	95
3	2.28	1.0	—	—	—	—	—	2,144	—
4	2.28	1.0	5.0	—	8.9	9.4	20	152	45
5	2.28	1.0	—	2.0	12.5	11.8	—	33	—
6	4.56	1.0	—	—	—	—	—	2,597	—
7	4.56	1.0	5.0	—	9.2	8.9	11	156	37
8	8.0	1.0	—	—	—	—	—	2,996	—
9	8.0	1.0	5.0	—	9.3	9.7	6.5	177	53
10	8.0	1.0	—	2.0	12.1	11.0	—	21	66
11	8.0	1.0	—	5.0	12.5	12.4	—	49	45

*These values were determined 0.5 hour after treating the suspension with $BaCO_3$ or $Ba(OH)_2$. Values after aging the muds were not appreciably different.

barium carbonate ineffective in this system. Further, since the pH of the muds used for parts C and D decreased to 11.8 and 10.0, respectively, with the barium carbonate treatment, the indications are that a pH of 10.0 is sufficiently high so that the reaction proceeds very slowly.

It should be noted that the pH of the low pH systems treated with $BaCO_3$ increased upon aging. This may be explained by the liberation of carbonate from the reaction:

$$BaCO_3 + SO_4^{=} \underset{\rightarrow}{\leftarrow} BaSO_4 + CO_3^{=} \quad . \quad . \quad . \quad . \quad (1)$$

The carbonate then hydrolyzes in water:

$$CO_3^{=} + H_2O \underset{\rightarrow}{\leftarrow} HCO_3^{-} + OH^{-} \quad . \quad . \quad . \quad . \quad (2)$$

In other words, the effect is analogous to the addition of a soluble carbonate which buffers the system.

The physical properties of the muds shown in Table II should be noted. Firstly, in the absence of any barium hydroxide or carbonate (tests 1, 2, 3, and 4) the viscosities and 10-minute gel strengths are increased by increasing the pH and the quebracho. Secondly, treatments with barium hydroxide did not adversely affect the properties of the muds and since it decreased the sulfate concentration more readily than the barium carbonate, the indications are that it could be used more advantageously than barium carbonate. This factor will be mentioned in another section.

In an attempt to determine more closely the effect of pH and of quebracho additional tests were conducted (Table III). For these tests, aqueous systems without clay were used. This simplified the experimental procedure as well as the interpretation of the results. For most of these tests sodium sulfate was used since it was realized that calcium sulfate would promote the reaction

$$BaCO_3 + SO_4^{=} \rightarrow BaSO_4^{=} + CO_3^{=} \quad . \quad . \quad . \quad . \quad (3)$$

by precipitation of the carbonate — at least in high pH systems — as calcium carbonate. When calcium sulfate is used one is assured that the amount of calcium which is present will be stoichiometrically equivalent to the carbonate liberated by the reaction given above.

Another major difference between the use of calcium and sodium sulfate in the presence of quebracho should be emphasized also. Addition of calcium sulfate to an alkaline quebracho solution precipitates some quebracho. The amount precipitated, on the basis of qualitative observations, is a function of pH (or NaOH), or ratio of sodium to calcium in the system. For example, quebracho is essentially insoluble in a saturated solution of calcium hydroxide (pH 12.6). The amount which will dissolve may be increased by addition of sodium hydroxide.

TABLE II

Removal of Sulfate with $BaCO_3$ and $Ba(OH)_2$ from aBentonitic Mud Containing Caustic and Quebracho

Composition of Stock Mud Used:

Water.....78.9%
Sodium hydroxide..... 0.226% (1.0 lb/bbl)
Quebracho..... 0.226% (1.0 lb/bbl)
Bentonite..... 6.4%
Barium Sulphate.....13.3%

Test No.	Total Present in Mud, lb/bbl					Initial pH*	API Code 29 Physical Properties After Aging Mud 16 hr. at 95° C.					$SO_4^{=}$ in filtrate from Aged Mud, ppm
	NaOH	Quebracho	$CaSO_4$	$BaCO_3$	$Ba(OH)_2$		Viscosity, cps	Init. gel, g.	10-min. gel, g.	Water-loss, ml/30 min.	pH of Mud	
A. Low pH—low quebracho												
1	1.0	1.0	1.0	—	—	8.5	16.5	0	2	11.3	8.4	2782
1a	1.0	1.0	1.0	5.0	—	8.5	75	0	2	7.0	8.9	267
1b	1.0	1.0	1.0	—	2.0	8.5	32	0	0	9.0	12.0	292
B. Low pH—high quebracho												
2	1.0	3.0†	1.0	—	—	8.3	29	0	12	10.0	8.3	3045
2a	1.0	3.0†	1.0	5.0	—	8.3	74	0	40	6.3	8.8	226
2b	1.0	3.0	1.0	—	2.0	8.3	59	0	20	6.3	9.8	251
C. High pH—low quebracho												
3	3.0	1.0	1.0	—	—	12.4	61	0	10	8.0	12.1	3053
3a	3.0	1.0	1.0	5.0	—	12.4	62	0	0	8.7	11.8	2609
3b	3.0	1.0	1.0	—	2.0	12.4	54	0	4	8.0	12.7	383
D. High pH—high quebracho												
4	3.0	3.0	1.0	—	—	11.9	70	0	20	6.0	10.4	2642
4a	3.0	3.0	1.0	5.0	—	11.9	60	0	7	6.7	10.0	2119
4b	3.0	3.0	1.0	—	2.0	11.9	71	0	2	7.2	12.2	383

*pH just prior to addition of $BaCO_3$ or $Ba(OH)_2$.
†The quebracho did not disperse completely in this mud upon stirring for 0.5 hr. at 25° C.

The results (Table III) show that in the absence of added alkali or quebracho (test No. 1) the sulfate was decreased to only 646 ppm. The pH of the suspension increased due to liberation of carbonate (reactions 1 and 2). For test No. 2, where 0.03 lb. NaOH per barrel was present, the result is essentially the same as for test No. 1. Tests 3, 4, and 5 show the effect of increasing the quebracho concentration to 2.3 lb./bbl. when the initial pH of the system is about 8.2. Compared with tests 1 and 2, the major effect of the quebracho appears to be a decrease in the rate at which the sulfate is removed, since the rate is markedly accelerated by heating the suspension.

Tests 6 and 7 (initial pH of 9.8) and test 8 and 9 (initial pH of 11.1-11.2) do not reveal any major effect of the quebracho in the concentration range of 1.2 to 2.3 lb./bbl., except that the value obtained for test 8 after aging seven days is about 25 per cent lower than for test 9. For all these tests the sulfate concentration remains high, and the overall data reveal that barium carbonate will not effectively remove sulfate from these sodium sulfate contaminated systems if the pH is higher than about 9.8 and when the quebracho is 1.2 lb./bbl. or more. However, when barium hydroxide (test 14) is used in place of the carbonate the sulfate is decreased to 29 ppm. in the high pH-high quebracho system which could not be treated with barium carbonate (test 9). Although carbonate ion concentrations in these systems were not determined, the success of the barium hydroxide treatment may be attributed in part to the fact that the carbonate ion concentration was decreased by the reaction:

$$Ba(OH)_2 + CO_3^{=} \rightarrow BaCO_3 + 2OH^- \quad . \; . \; . \quad (4)$$

The excess barium hydroxide was then available to precipitate the sulfate. The effect of carbonate ion concentration will be discussed in a later section.

When calcium sulfate is used as the contaminant (tests 10-13), the sulfate is effectively removed by barium carbonate in the absence of quebracho, but when the quebracho is increased to 1.2 or 2.3 lb./bbl. as for tests 12 and 13, the sulfate is but slightly decreased.

It was expected, at first, that these tests would show definite limits for both the pH of the system and the concentration of quebracho in order for the sulfate to be precipitated completely by barium carbonate. The tests show no sharply defined limits for either of these two factors and merely show that the barium carbonate treatment may not be effective. Treatments with barium hydroxide, however, were effective under conditions for which barium carbonate was not. This emphasized that removal of sulfate from such systems was not an impossibility. A study of the factors involved, as presented in Section IV of this report, showed that *no sharply defined limits could be expected*. Rather, a multi-component system is involved and the extent of the reaction (equilibrium) is controlled by the components and their concentration in the system at equilibrium. A knowledge of the effect of these variables can then be used to determine either the conditions under which barium carbonate may completely precipitate the sulfate or indicate treatments which are required to render the precipitation complete.

THEORETICAL DISCUSSION

The limited tests which have been presented show that treatment with barium carbonate is far from a simple panacea for the difficulties which may be encountered due to sulfate contamination in a drilling fluid. The tests have also served to show that certain factors, not readily apparent from the data, are involved which require an explanation.

Consider the reaction which is involved in the precipitation of sulfate by barium carbonate:

$$BaCO_3 \text{ (excess)} + SO_4^{=} \rightleftarrows BaSO_4 + CO_3^{=} \quad . \quad (5)$$

For this reaction the equilibrium constant is given by the equation

$$K_1 = \frac{{}^a CO_3^{=}}{{}^a SO_4^{=}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

where ${}^a CO_3^{=}$ and ${}^a SO_4^{=}$ are the activities of the carbonate and sulfate ions in the solution at equilibrium. Using the values for the solubility product constants for barium sulfate and barium carbonate as reported by Latimer[6].

$$K_{BaSO_4} = ({}^a Ba^{++} \; {}^a SO_4^{=}) = 9.9 \times 10^{-11} \quad . \; . \quad (7)$$

and

$$K_{BaCO_3} = ({}^a Ba^{++} \; {}^a CO_3^{=}) = 4.93 \times 10^{-9} \quad . \; . \quad (8)$$

the value of K_1 in equation (6) may be evaluated

TABLE III

Removal of Sulfate from Aqueous Suspensions

Test No.	In Suspension lb/bbl						pH of Suspension			ppm of SO_4			
	NaOH	Quebacho	Na_2SO_4	$CaSO_4$	$BaCO_3$	$Ba(OH)_2$	Before addn. of Ba	5 min. after addn.	24 hr. after addn.	Add'd	Found (1 day)	Found* (1 day)	Found 7 days
1	0	0	1.17	—	5.0	—	6.0	10.7	11.3	2250	646	582*	—
2	0.03	0	1.17	—	5.0	—	10.8	10.9	11.4	2250	640	578*	—
3	0.03	0.58	1.17	—	5.0	—	8.1	9.7	10.4	2250	944	922*	
4	0.06	1.2	1.17	—	5.0	—	8.2	9.1	9.8	2250	1,067	695*	
5	0.12	2.3	1.17	—	5.0	—	8.2	8.7	9.3	2250	1,066	702*	
6	0.23	1.2	1.17	—	5.0	—	9.8	9.8	10.1	2250	1,511	—	
7	0.47	2.3	1.17	—	5.0	—	9.8	9.8	9.9	2250	1,621	—	
8	0.47	1.2	1.17	—	5.0	—	11.1	11.0	11.0	2250	1,906	—	1440
9	0.93	2.3	1.17	—	5.0	—	11.2	11.2	11.1	2250	1,910	—	1903
10	0	0	—	1.17	5.0	—	6.3	9.8	9.5	2350	8	—	
11	0.03	0	—	1.17	5.0	—	11.2	11.2	11.0	2350	14	—	
12	0.47	1.2	—	1.17	5.0	—	10.7	10.6	9.6	2350	1,891	—	1918
13	0.93	2.3	—	1.17	5.0	—	10.7	10.6	9.9	2350	2,237	—	2319
14	0.93	2.3	1.17	—	—	2.0	10.7	—	12.6	2250	29	—	

*Just prior to filtration, the suspensions were heated to boiling and cooled to room temperature with continous stirring for one hour.

$$K_1 = \frac{{}^a CO_3^{=}}{{}^a SO_4^{=}} = \frac{4.93 \times 10^{-9}}{9.9 \times 10^{-11}} = \text{about } 50 \quad . \quad (9)$$

It should be stated that other values in the literature for the solubility product constants for barium sulfate and carbonate vary by a factor of about 5 from those given by Latimer. This fact does not invalidate the discussion which follows; and it is believed that Latimer's data is the most consistent with other data in the literature, and will be used for the source of other solubility product data herein reported.

Since the activity of an ion is equal to its concentration, m, multiplied by its activity coefficient, γ, equation (9) may also be written as:

$$K_1 = \frac{({}^m CO_3^{=} \ \gamma \ CO_3^{=})}{({}^m SO_4^{=} \ \gamma \ SO_4^{=})} = \text{about } 50 \quad . \ . \ . \quad (10)$$

For any finite concentration the activity coefficients are generally less than unity and are functions of the average ionic strength, μ, of the solution. The ionic strength[7] is defined by

$$\mu = \frac{Z^2 + m^+ + Z^- m^-}{2} = 1/2 \ \Sigma \ m_i Z_i^2 \quad . \ . \quad (11)$$

where Z_+ and Z_- are the charges of the positive and negative ions, respectively, in solution at concentrations m^+ and m_-. Thus, unless the activity coefficients of the sulfate and carbonate ions in a given solution are equal, the mol ratio (as determined by solubility) of the carbonate to sulfate ion for equation (9) need not be equal to 50. If the activity coefficient of the sulfate ion is lower than that of the carbonate ion at any given ionic strength, the mol ratio will be less than 50. That this is true was shown by inspection of values for the activity of potassium carbonate and of potassium sulfate at corresponding concentrations as reported by Latimer[6]. Calculation of the individual ion activities, ${}^a CO_3^{=}$ and ${}^a SO_4^{=}$, using values reported for K_2SO_4, K_2CO_3 and KCl at corresponding ionic strengths, revealed that for values of ionic strengths greater than about 0.003, the activity of the carbonate was greater than that of the sulfate ion.

The above discussion can be summarized as follows. In any simple system saturated with barium sulfate and barium carbonate: (a) the mol ratio of carbonate to sulfate in solution will be less than the value of 50 indicated by the equilibrium constant for the system, (b) the concentration of sulfate ion will be increased by addition of soluble carbonates or by other electrolytes (NaOH, NaCl) not having the common ion Ba^{++}.

Supporting these conclusions are data reported in Table IV taken from the International Critical Tables. The last three columns of the table were computed from the data in order to report the concentrations in familiar terms.

In view of the previous discussion little need be said about these data. The equilibrium constant, K_m, reported in the table represents the mol ratio of carbonate to sulfate in the mixtures at equilbrium. It can be seen that this ratio decreases rapidly with increase in ionic strength of the solution. The data of part A of Table IV show that the ratio is highly dependent on temperature, so that at 100 C. the removal of sulfate from the potassium sulfate solution by barium carbonate is not as effective as at 25 C.

Part B of Table IV is quite analogous to that of Part A except that barium chloride was used so that the solution in equilibrium contains potassium chloride. This, in effect, increases the ionic strength of the solution and the equilibrium constant, K_m, given by the ratio of the moles of carbonate to moles of sulfate in solution is decreased. The data in Part B do not indicate high dependence on temperature.

The data of Table IV, and the theoretical treatment given, apply only to simple systems involving the equilbrium between barium carbonate and barium sulfate with sulfate and carbonate ions. In drilling mud systems the situation becomes far more complicated, but some of the factors may be partially evaluated by comparison with the effect in the simple system which was considered.

1. Effect of the concentration of carbonate: Obviously, the reaction

$$BaCO_3 + SO_4^{=} \rightleftarrows BaSO_4 + CO_3^{=} \quad . \ . \ . \quad (5)$$

can be made to proceed to completion by removal of the carbonate. The procedure employed is to add calcium (as lime) to precipitate calcium carbonate. Complete removal of carbonate by calcium would be favored by a pH sufficiently high

TABLE IV

Equilibria in Aqueous Systems Containing Barium Sulfate and Barium Carbonate. Data from International Critical Tables, Vol. VII, p. 300

Part A.

Reaction: $BaCO_3(s) + SO_4^{=} \rightarrow BaSO_4(s) + CO_3^{=}(?)$*

$K_{298.1} = Ca25$

In Solution, moles/1000 g of H_2O		Ionic Strength μ	Equil. Constant, Km	In Solution, ppm of Water		
K_2SO_4	K_2CO_3			SO_4	CO_3	Cl-
		t=25° C.				
0.00331	0.0690	0.217	20.9	318	4,140	—
.01218	.1873	.598	15.4	1,170	11,230	—
.0580(s)	.5243	1.747	9.03	5,570	31,400	—
		t=100° C.				
.01533	.0571	0.217	3.73	1,470	3,430	—
.03639	.1131	.448	3.11	3,500	6,790	—
.2279(s)	.4144	1.927	1.82	21,850	24,860	—

Part B.

K_2SO_4 (aq) and K_2CO_3 (aq) by $BaCl_2$ (aq); the solid phases may not be pure;

$K_{298.1} = ca\ 8.$

In Solution, moles/1000 g of H_2O			Ionic Strength, μ	Equil. Constant, Km	In Solution, ppm of Water		
K_2SO_4	K_2CO_3	KCl					
			t=20° C.				
0.0005	.0072	.00068	.0238	14.5	48	432	241
.0009	.0068	.00068	.0238	7.6	86	408	241
.0028	.0164	.0017	.0593	5.9	269	984	602
.0032	.0160	.0017	.0593	5.0	307	960	602
.0147	.0619	.0068	.2366	4.2	1,410	3,710	2,410
.0159	.0607	.0068	.2366	3.8	1,530	3,640	2,410
.096	.287	.034	1.183	3.0	9,220	17,200	1,200
.104	.279	.034	1.183	2.7	10,000	16,940	1,200
			t=96° C.				
.083	.300	.034	1.183	3.6	7,970	18,000	1,200
.089	.294	.034	1.183	3.3	8,540	17,600	1,200

*This question mark suggests that the carbonate would be hydrolyzed to HCO_3, that the original data did not indicate ratio of carbonate to bicarbonate in solution, and that the bicarbonate is reported as carbonate.

(>10) so that bicarbonate is eliminated. However, in view of the fact that the solubility product for calcium carbonate

$$CaCO_3 \rightleftarrows Ca^{++} + CO_3^{=}; \quad K = 4.82 \times 10^{-9} \quad . \; . \quad (12)$$

is but slightly less than that for barium carbonate

$$BaCO_3 \rightleftarrows Ba^{++} + CO_3^{=}; \; K = 4.93 \times 10^{-9} \quad . \; . \; . \quad (13)$$

the effect of lime *in the presence of excess barium carbonate* is due not only to removal of carbonate but also to decomposition of barium carbonate according to the equation:

$$BaCO_3 + Ca(OH)_2 \rightarrow Ba(OH)_2 + CaCO_3 \quad . \; . \quad (14)$$

The effective concentration of the barium ion is thereby increased with a proportional decrease in the sulfate concentration. Obviously, application of barium hydroxide, rather than barium carbonate and lime, for the precipitation of sulfate, is a direct approach. The use of barium hydroxide is particularly indicated when the sulfate contamination is not primarily due to anhydrite (calcium sulfate) or when the carbonate concentration in the mud is high. Under these conditions the barium carbonate treatment can only be effective when lime or other soluble calcium or barium salt is added so that the carbonate ion concentration will be decreased.

2. Effect of pH: The effect of pH has been briefly mentioned. In the simple system — $BaCO_3$, $BaSO_4$, H_2O — it was assumed that only the carbonate ion was present. In reality, the carbonate ion hydrolyzes in water:

$$CO_3^{=} + H_2O \rightarrow HCO_3^{-} + OH^{-} \quad . \; . \; . \; . \; . \quad (15)$$

so that appreciable bicarbonate may be present unless the hydrolysis is represses by addition of alkali. If acid is added to the system, the following equilibria become involved:

$$HCO_3^{-} \rightleftarrows H^{+} + CO_3^{=}; \quad K = 4.7 \times 10^{-11} \quad . \; . \; . \quad (16)$$

and

$$H_2CO_3 \rightleftarrows H^{+} + HCO_3^{-}; \quad K = 4.3 \times 10^{-7} \quad . \; . \quad (17)$$

(In a given system, the pH will determine the ratio of carbonate to bicarbonate ion in solution.)

Therefore, a decrease in pH promotes the reaction

$$BaCO_3 + H^{+} \rightarrow Ba^{++} + HCO_3^{-} \quad . \; . \; . \; . \quad (18)$$

The barium ion concentration is increased, and the sulfate ion concentration would be decreased in accordance with the solubility product for barium sulfate as previously given.

In terms of drilling mud practice, two pH ranges may be considered. In high pH (> 11) where bicarbonate ion is practically eliminated, the effective removal of sulfate by barium carbonate requires that the carbonate be removed.

In such high pH systems the removal of carbonate could be effectively accomplished by addition of a soluble calcium or barium compound. In connection with this, it should be emphasized that even if the sulfate contamination is from anhydrite, the amount of calcium in the system may be stoichiometrically less than that required to remove the carbonate. Alkaline muds would pick up carbonate from decomposition of organic matter in the system and from absorption of carbon dioxide from the atmosphere. There would also be some adsorbtion of calcium on the clay present.

In low pH systems, the carbonate may not be effectively decreased by calcium. Effective removal of sulfate would then depend upon increasing the concentration of barium ion. This could be accomplished by lowering the pH to dissolve barium carbonate or by addition of a soluble barium salt (e.g. $BaCl_2$).

3. Effect of inorganic ions which may or may not react with components of the system: The effect of ions which do not enter into the reaction was shown to result in an increase in the ionic strength with a resulting increase in the amount of sulfate which may remain in solution at equilibrium. The data of Table IV could be used to estimate the concentration of sulfate which would exist in the solution at equilibrium for values of ionic strength up to 1.9. The presence of such electrolytes puts a premium upon either the effective decrease in the carbonate ion concentration (by addition of calcium) or an increase in the concentration of barium (by decrease in pH to solubilize $BaCO_3$ or addition of a soluble barium compound).

In the presence of other constituents which may form precipitates with barium ion, the solubility product relationships for all the insoluble products must hold simultaneously. Consequently, any ion which forms with barium a compound having a low solubility product may be suspected as an interfering substance. For example, one such interfering ion might be chromatic which is added to some drilling muds to inhibit corrosion:

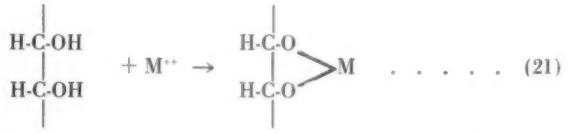
$$BaCrO_4 = Ba^{++} + CrO_4^{=}; \quad K = 2 \times 10^{-10} \quad . \; . \quad (19)$$

Others might include permanganate and metasilicate:

$$Ba(MnO_4)_2 = Ba^{++} + 2MnO_4^{-}; \quad K = 2.5 \times 10^{-10} \quad (20)$$

No solubility product data were found for barium metasilicate; but the solubility is believed to be low. Considerable silicate should be present particularly in high pH muds. In such systems the alkali would decompose the clay with the formation of soluble silicates. As indicated in the introduction, the phosphates also precipitate, or form complexes with barium ion.

4. The effect of quebracho and other organic matter: The fact that quebracho renders the barium carbonate treatment ineffective for removal of sulfate suggests that the barium ion forms a complex with or precipitates quebracho. It is well known that quebracho or other tannins may form precipitates with metal ions. However, even if a precipitate is not formed, organic material, particularly those containing hydroxyl groups, frequently form extremely stable complexes with polyvalent metal ions. A classic example of this phenomenon is the formation of complexes with tartrate or oxalate for which the reaction is formulated as



. . . . . (21)

where M^{++} represents any divalent metallic ion. The complexes thus formed are frequently so stable that qualitative tests for the metal ion in such solutions may not reveal the presence of the metallic constituent until the organic matter is destroyed. Obviously to overcome the effect of such organic material a considerable excess of barium carbonate must be used or else the organic matter must be removed or its concentration decreased.

5. The effect of the clay: In drilling mud systems the effect of the clay will always be a factor. Firstly, clays, particularly those with a high base exchange capacity, will con-

tribute to the ionic strength of the system. This effect may be small except in high pH systems where sorption of hydroxyl ion is appreciable so that highly charged particles are formed.

Secondly, clays could undergo base exchange reactions. At pH values much below 9, the concentration of barium derived from solution of barium carbonate would certainly be sufficiently high so that an appreciable amount of barium would be exchanged for other cations sorbed on the clay. Further, in view of the very low activities which have been reported[8] for monovalent cations in clay suspensions at pH values to about 11, it is quite probably that the concentration of barium ion derived from barium carbonate in most muds would be sufficiently high so that barium would be exchanged for other ions adsorbed on the clay.

It should be mentioned that in publications concerning drilling muds the statement is frequently made that chemicals having a low solubility in water are "inert" materials toward the clay. As shown by the data herein reported, even barium sulfate, which has an exceedingly low solubility in pure water, cannot be considered an inert material. For example, upon addition of barium sulfate to a mud containing carbonate considerable barium sulfate may be dissolved and affect the properties of the clay.

SUMMARY

The factors involved in the removal of sulfate from aqueous systems or drilling muds when using barium carbonate have been presented in considerable detail. The experimental data and the theoretical discussion have emphasized that the precipitation of sulfate by barium carbonate may not be as effective as generally presented in the literature and that the concentration of sulfate remaining in the system at equilibrium may be high. The amount of sulfate remaining in solution at equilibrium was shown to be primarily a function of the carbonate ion concentration, the barium ion concentration, and the ionic strength of the system. In addition, the presence of interfering substances — those which form difficulty soluble compounds or complexes with barium — may complicate the removal of sulfate by barium carbonate. A thorough comprehension of these factors should permit more fruitful application of the treatment.

Successful treatment of a drilling mud for removal of sulfate with barium carbonate requires at least that either the barium carbonate be appreciably solubilized (by having a low pH) or that the carbonate ion concentration be kept low. A decrease in the concentration of carbonate ion can be achieved by addition of a soluble calcium or barium salt (for example, calcium hydroxide or barium hydroxide). Complete precipitation of carbonate as the calcium or barium salt is favored by a high pH. For these reasons, the use of barium hydroxide is particularly indicated when the sulfate contamination is not primarily due to anhydrite or when the carbonate concentration in the mud is high.

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DISCUSSION

By O. W. Van Dyke, Magnet Cove Barium Corp., Houston, Texas

I would like to compliment Bergman, Fisher and Carpenter for the work that they have reported in this paper. We should also express appreciation to the Phillips Petroleum Co. for making this work possible.

This paper is of particular interest because it reports the results of research into a seemingly very simple chemical reaction that has been used in mud treating for quite a long time. It is work such as this that is bringing about refinements in drilling mud control that are necessary for today's deep holes. The authors have explained with experimental data the reason for some of the erratic behaviors we have all observed in using barium carbonate for removing sulphate from drilling mud. These data point out that pH, carbonate content, presence of quebracho or other complexing agents are only a few of the factors influencing the results that might be expected when using barium carbonate for the removal of sulphate. This work certainly points out that the reactions involving barium carbonate in drilling mud are complex and effected by numerous conditions.

It would have been of interest to have had some consideration given to the removal of calcium as well as the sulphate ion because such cations have a much greater effect upon mud than anions such as sulphate. We have done work which indicates that the sulphate ion is no more detrimental to drilling mud than the chloride ion. The fact that the sulphate ion usually enters the mud as calcium sulphate has perhaps prompted the misnomer of "sulphate contamination" for calcium sulphate where the major offender actually is the soluble calcium rather than the sulphate ion. In view of the fact that the most common application for barium carbonate has been treating out the detrimental effects of calcium sulphate, specific reference to this problem would have been timely in this paper.

DISCUSSION

By G. E. Saunders, Sohio Pet. Co., Cleveland, Ohio

This paper furnishes the industry with some very good theoretical data concerning sulfate removal in drilling muds.

One of the conclusions very worthwhile is that a high pH and high quebracho mud greatly reduces the effectiveness of the barium carbonate treatment. In this case, would the recommended testing procedure be to dilute the system with water in order to lower the pH and then carry on routine carbonate treatment?

It seems that some tests would have been advisable concerning the use of sodium carbonate, particularly when the sulfate content is due primarily to gypsum in low concentrations.

Barium hydroxide was shown to be much more effective in sulfate removal in some types of mud. The question arises as to cost and availability of the hydroxide instead of the carbonate. Barium carbonate is a native material, quite cheap and found in large quantities. It seems that using an excess (as is usually done in the field) of perhaps 15 to 20 pounds per barrel might be a more economical treatment.

The fact that high pH and high quebracho content in the mud inhibits the carbonate reaction should be very useful information. In some instances, such as at Carthage, Texas, anhydrite is found at known depths and the mud engineer can keep the pH and quebracho content at low values so that the carbonate will be effective when anhydrite is encountered.

Additional work in connection with sulfate removal where the treatment is done with polyphosphates instead of carbonates would be very useful to the industry.

Authors' reply to O. W. Van Dyke

The authors wish to point out that this paper has been purposely directed toward an emphasis on removal of sulfate ion. While sulfate may be no more detrimental than chloride or certain other inorganic anions, there are field problems in which even relatively small concentrations of sulfate arising possibly from the mud make-up water, may contribute to the difficulty or complexity of maintaining specific mud properties, for example, low 10 minute gel strengths. The cations present are relatively unimportant in cases such as these.

The problems of muds heavily contaminated with anhydrite certainly poses the additional problem of handling the calcium ions in many of the methods of treating these muds. In the case of treatment with sodium carbonate or sodium hydroxide, the resultant high concentration of sulfate demands either a special mud to handle the sulfates or a method for their removal. This paper has made no attempt to answer all the ramifications of this system and the resultant effects on the mud properties.

Authors' reply to G. E. Saunders

In the case of the high-pH, high-quebracho systems, water dilution may be preferred particularly if no expenditure of weighting agent or other chemicals is required upon dilution. Treatment with sodium carbonate to precipitate the calcium might be recommended if the amount of anhydrite is small. Treatment with barium carbonate might be preferable if pilot tests indicate that the treatment is effective. It should be emphasized that where barium carbonate does not function the use of an excessive amount, as is sometimes done in the field, is unwarranted. The only alternative is to condition the system so that the barium carbonate will function or to use barium hydroxide. ★ ★ ★

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